Geology and Petrology of the Ute Mountains Area Colorado

GEOLOGICAL SURVEY PROFESSIONAL PAPER 481

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

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By E. B. EKREN *and* F. N. HOUSER

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The petrography, structure, and petrology of a laccolithic mountain range on the Colorado Plateau

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By E. B. Ekren and F. N. Houser

ABSTRACT

The Ute Mountains area is on the Colorado Plateau in the southwest corner of Colorado, in Montezuma County, about 20 miles northeast of the Four Corners where Colorado, Utah, Arizona, and New Mexico join. The mountains are a laccolithic group that rises to an altitude of nearly 10,000 feet and stands 2,500 to 4,000 feet above the surrounding area.

Sedimentary rocks exposed in the Ute Mountains area aggregate about 3,800 feet in thickness and are of Triassic(?), Jurassic, Cretaceous, and Quaternary age. The Triassic(?) and Jurassic rocks in the area include the Navajo Sandstone, the San Rafael Group, and the Morrison Formation. Cretaceous rocks include the Burro Canyon Formation, the Dakota Sandstone, the Mancos Shale, and basal beds of the Point Lookout Sandstone of the Mesaverde Group. Tertiary and Cretaceous rocks younger than the lowermost beds of the Point Lookout Sandstone have been removed by erosion.

The physical characteristics of the Navajo Sandstone (oldest formation exposed) and formations of the San Rafael Group are similar and indicate alternating subaerial and subaqueous deposition. These formations are predominantly cross-stratified sandstone that was deposited in an eolian environment, but include beds of flat-stratified sandstone, siltstone, and mudstone that apparently were deposited in a marine or lacustrine environment. The Morrison Formation in the Ute Mountains area is composed of fluvial and flood-plain deposits, and comprises four members: the Salt Wash Sandstone Member, Recapture Shale Member, Westwater Canyon Sandstone Member, and Brushy Basin Shale Member. The lower two members, Salt Wash and Recapture, and the upper two members, Westwater Canyon and Brushy Basin, intertongue and intergrade to a considerable extent. The Burro Canyon Formation consists of discontinuous fluvial conglomeratic sandstone lenses and interbedded mudstone and claystone. In places only mudstone is present. The mudstone weathers hackly or fissile and can be easily distinguished from that of the Brushy Basin Member of the Morrison Formation, which weathers to a hard and frothy-appearing material because of abundant bentonite. The Dakota Sandstone consists predominantly of fluvial sandstone and interbedded carbonaceous shale. Although the Dakota Sandstone is separated from the Burro Canyon Formation by a disconformity, the two formations are similar and, in places, their distinction is difficult. The Mancos Shale in the Ute Mountains area consists of approximately 1,900 feet of dark-gray gypsiferous mudstone. The formation contains abundant marine fossils and two conspicuous lithologic marker units. The Greenhorn Limestone Member is about 75 feet from the base, and consists of 15 to 35 feet of dense gray limestone and interbedded gray mudstone. The Juana Lopez Member is about 475 feet above the base of the Mancos; it consists of 3 to 50 feet of thin-bedded tan sandy fossiliferous limestone and was mapped to include an overlying light-gray glauconitic coarse-grained sandstone. Overlying the Mancos Shale on a few high places in the Ute Mountains are thin flat-stratified persistent beds of buff and yellowish-gray sandstone interstratified with dark-gray mudstone similar to the Mancos. This sequence is probably the basal part of the Point Lookout Sandstone of the Mesaverde Group.

The igneous rocks in the Ute Mountains intrude beds of the Point Lookout Sandstone of Late Cretaceous age. This evidence is the only direct indication available of the age of the intrusive rocks in the Utes. The lack of coarse detritus in Upper Cretaceous rocks that crop out a few miles east of the Ute Mountains, and that are younger than the Point Lookout Sandstone but older than the McDermott Member of the Animas Formation of late Cretaceous and Paleocene age indicates that igneous activity and accompanying uplift did not occur prior to the deposition of the McDermott. The McDermott Member contains abundant andesite boulders probably derived from the La Plata Mountains, a laccolithic group lying 35 miles east of the Ute Mountains and presumably of the same age as the intrusive rocks of the Ute Mountains. The occurrence of andesite boulders in the McDermott may indicate a precise age for the laccolithic mountains on the Colorado Plateau.

The igneous rocks of the Ute Mountains form a differentiated calc-alkaline series that ranges from microgabbro through quartz monzonite. Field mapping indicates that the earliest intrusive rock was microgabbro, followed by diorite, granodiorite, and finally quartz monzonite. All the igneous bodies were intruded forcibly into sedimentary rock. No evidence of wallrock replacement or assimilation was found. The textures of the igneous rocks vary with rock type and from one intrusive body to another. In general, the microgabbros are slightly porphyritic, the diorites moderately porphyritic, and the granodiorites and quartz monzonites conspicuously porphyritic. The groundmasses of the different types of rock make up from 40 to 60 percent of the volume and, in general, are dense; grains range in size from less than 0.01 mm to about 0.1 mm.

Chemical analyses of 16 samples of igneous rocks from the Ute Mountains reveal that silica ranges from about 50 percent in the microgabbro to almost 69 percent in the quartz monzonite; alumina content is nearly constant (about 17 percent for all the rocks in the series); total iron, magnesia, and lime decline from high values in the microgabbro to low values in the quartz monzonite; Na_2O and K_2O show distinct increases from relatively low values in the microgabbro to higher values in the quartz monzonite.

Semiquantitative spectrographic analyses indicate that several minor elements show distinct trends. The systematic variation of the major and minor elements suggests that the igneous rock series in the Ute Mountains resulted from differentiation of a single-source magma.

Hornblende-rich inclusions are abundant in the igneous rocks, particularly in the diorite and granodiorite. The hornblende in the inclusions is not distinguishable optically or chemically from the hornblende of the phenocrysts. Chemical, optical, and spectrographic analyses of hornblende from two inclusions and phenocrysts from two porphyries are so similar that a common origin is inferred. Two such origins seem most probable: the inclusions are either fragments of early differentiates, or fragments derived from a deep hornblendic substratum from which the Ute magma itself was derived.

The largest structural features in the Ute Mountains area are Ute and McElmo domes. Ute dome is nearly circular in plan view and averages about 10 miles in diameter, although the western margin is poorly defined. The relief on the dome ranges from only about 400 feet on the north, where it is in contact with McElmo dome, to more than 2,000 feet on the south. The top of the dome appears to be flat, but is complicated in detail by the occurrence of numerous laccoliths and three stocks. Ute dome is thought to be entirely the result of forceful injection of magma, most of the doming being caused by the injections of three stocks. McElmo dome is also nearly circular in plan view, but the flanks of the dome pass into a series of radiating anticlines. The total area affected by McElmo dome and its satellitic anticlines measures about 20 miles east to west and 10 miles north to south. The dome has about 500 feet of closure. The origin of McElmo dome and its relation to Ute dome is uncertain, but the proximity of the two suggests that they are related genetically. The general lack of igneous rock at depth in McElmo dome, however, suggests that most of the structural relief may be a result of basement uplift related to Late Cretaceous or early Tertiary folding recognized elsewhere on the Colorado Plateau.

Steeply dipping normal faults of small displacement occur on the north, west, and south flanks of Ute dome, and on the southwest flank and in the central part of McElmo dome. No postintrusive faults were noted on the steeply dipping east flank nor in the central part of Ute dome, but preintrusive fracture zones appear to have controlled emplacement of some igneous bodies. The possibility exists, therefore, that many of the faults and fractures are earlier than Ute dome and reflect a zone of weakness in the basement that localized the igneous activity in the Ute Mountains.

Intrusive rocks in the Ute Mountains form laccoliths, bysmaliths, sills, and dikes, in addition to stocks. In general, the least siliceous rocks occur as sills or flat-topped laccoliths; and the more siliceous intrusive rocks occur as mushroom-shaped laccoliths and bysmaliths. Dikes occur mainly adjacent to the stocks. Most of the intrusive rocks (excluding dikes) probably were fed laterally from the three stocks.

Deposits of uranium, vanadium, and copper occur in McElmo Canyon. Although these deposits are small and currently have no commercial value, they are of considerable geologic interest. Uranium and vanadium occur in the Karla Kay Conglomerate Member of the Burro Canyon Formation and in the Entrada Sandstone. Uranium, traces of copper, and abundant barite occur in faults northwest of the Ute Mountains. Copper, barite, and traces of lead, zinc, and silver occur in nonradioactive deposits in faults that lie between the intensely altered Mable Mountain bysmalith and the uranium deposits. The Mable Mountain bysmalith is cut by a fracture zone and has been intensely mineralized with iron sulfides. The copper deposits and the fault-controlled uranium deposits are spatially related to the Mable Mountain fracture zone and may be genetically related to the Ute igneous activity. The uranium was probably deposited by ascending solutions that also carried copper. The ubiquity of barite in both the radioactive and nonradioactive deposits suggests that the deposits are related to the Ute igneous rocks, which are relatively rich in barium. No evidence was found that directly related the uranium deposits in beds of conglomerate and sandstone to the fault-controlled deposits. The minor elements of the two types of uranium deposits and the nonradioactive copper deposits are similar. The possibility exists, therefore, that the bedded deposits of the McElmo Canyon area are related to the Ute igneous activity.

The oil and gas possibilities of the Ute Mountains area have been enhanced by the discovery of several major oil fields in southeastern Utah. Both McElmo dome and Ute dome are potentially excellent structural traps for oil. McElmo dome, however, by 1958 had been tested by six wells drilled on or near the crest of the structure, only one of which yielded hydrocarbons. This well produces natural gas from the Shinarump Member of the Chinle Formation and had an initial potential of 500,000 cubic feet of gas per day. Carbon dioxide was found in three other wells in Mississippian and Lower Cambrian rocks, and two of these were completed as carbon dioxide wells. The paucity of oil and flammable gas in McElmo dome and the abundance of carbon dioxide have discouraged exploration. The origin of carbon dioxide in the McElmo structure is unknown, but probably is related to igneous intrusion either directly beneath McElmo dome or in the Ute Mountains. Carbon dioxide probably occurs in the Ute dome and may completely fill the potential reservoir rocks.

The Dakota Sandstone in the Ute Mountains area contains many thin beds of coal, which, with few exceptions, are lenticular and have no commercial value at present.

INTRODUCTION

This report describes the geology of the Ute laccolithic mountain group on the Colorado Plateau and particularly the stratigraphy of the sedimentary rocks exposed in the area surrounding the mountains, the petrography and petrology of the igneous rocks, the structure of the sedimentary and igneous rocks, and the economic geology.

GEOGRAPHIC SETTING AND ACCESSIBILITY

The Ute Mountains area (fig. 1) is in the southwest corner of Colorado, in Montezuma County, about 20 miles northeast of the Four Corners where Colorado, Utah, Arizona, and New Mexico join. The mountains extend about 8 miles from north to south and 7 miles at the widest part from east to west. McElmo Canyon lies just north of the Ute Mountains. The west-trending canyon cuts into the broad McElmo dome, which is about 8 miles in diameter.

From the Ute Mountains area, the La Plata Mountains are visible to the east, the Abajo Mountains to the northwest, the Carrizo Mountains to the south, and Ship Rock, the famous volcanic neck in northwestern New Mexico, is visible to the south-southeast.

The Ute Mountains area is accessible from Cortez, Colo., by U.S. Highway 666 to the Ute Reservation

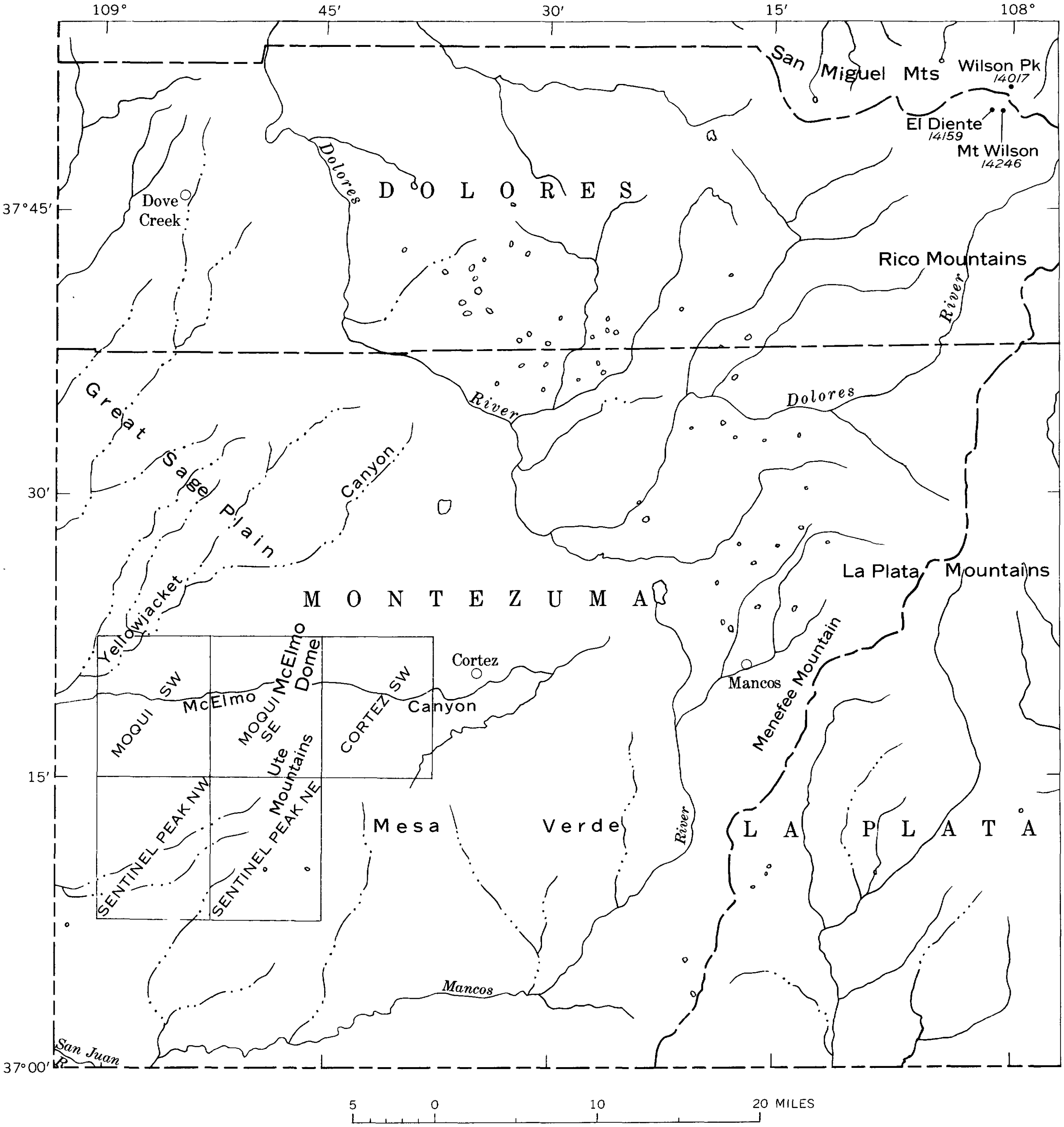


FIGURE 1.—Index map of southwestern Colorado showing quadrangles mapped in the Ute Mountains area.

Road to Towaoc, Colo., and by State Highway 32 through McElmo Canyon. A road passes south of the mountains to Aneth, Utah. Roads have been constructed through parts of the eastern half of the mountains by the Ute Mountain Tribal Council since the conclusion of the field study. Many of these roads open areas that during mapping were reached on foot.

Cortez is serviced by bus, truck, and airlines. The nearest railroad is at Durango, Colo., 48 miles east of Cortez, and can be reached by U.S. Highway 160.

CULTURE

The Ute Mountains are the site of the Ute Mountain Indian Reservation, which covers most of the area mapped except McElmo Canyon and its tributaries west of the mountains. Most residents of the Ute Mountain Reservation make their permanent homes at Towaoc, Colo., which is the headquarters of the Ute Mountain tribe and the location of the local agency of the U.S. Bureau of Indian Affairs. A store, restaurant, filling station, and school are available at Towaoc. During the summer months, many Indian families move into the mountains where they hunt and herd sheep. Income from land royalties during recent years has enabled the Ute Indians to raise their standard of living and to make significant capital investments in a water system and in livestock.

Alluvium in Montezuma Valley and McElmo Canyon (pl. 1) supports small but productive fruit, small grain, and cattle ranches. The alluvium occurs at low elevations and irrigation is necessary. Dry farming of pinto beans and wheat is profitable on higher mesas on the north flank of McElmo dome and on the plains north of the city of Cortez.

TOPOGRAHY

The Ute Mountains rise 2,500 to 4,000 feet above the surrounding area, which ranges in altitude from 4,800 feet in McElmo Canyon to 6,000 feet on mesas north of McElmo Canyon. The altitude of Ute Peak is 9,977 feet, of Black Mountain 9,405 feet, and of Hermano Peaks ("The Knees") in the south-central part of the mountains 8,960 feet. Although moderately sharp ridges and intervening valleys make up most of the range, a few topographic benches occur on flat-topped laccoliths.

From the east, the view of the mountain range is striking. It has led many to visualize a man lying on his back, with his head to the north, his feet to the south, his arms folded upon his chest, and his face turned toward the setting sun. This configuration has led to the popular name, Sleeping Ute or Sleeping Ute Mountain.

Various ridges and peaks of the range are known locally by the parts of the "Sleeping Ute" that they represent. Thus, Mable Mountain represents the head, Ute Creek dike the headdress, Ute Peak the arms folded over the chest, and Hermano Peaks the knees. Sentinel Peak in the southeast part of the mountains and a topographically similar peak in the southwest are the large toes, termed, respectively, East Toe and West Toe.

The east, south, and west sides of the mountains blend gently with the plains or mesas of the Colorado Plateau, at altitudes between 5,000 and 5,500 feet above sea level. On the north side, McElmo Creek has cut a deep west-trending canyon through the southern flank of McElmo dome.

CLIMATE AND VEGETATION

The climate of the area is semiarid. McElmo Creek is the only perennial stream, but springs are abundant in the mountains, and some of them flow throughout the year.

Rainfall and temperature recorded (table 1) at Mancos, Colo., 25 miles to the east, indicate approximate rainfall and temperatures in the Ute Mountains, inasmuch as the altitude of 7,035 feet at Mancos is close to the mean altitude of the Ute Mountains. Thunderstorms are common over the mountains in summer and early fall months. Prevailing winds are from the southwest.

TABLE 1.—*Average rainfall and temperature at Mancos, Colo., 1898–1919*

[After U.S. Department of Agriculture (1936, sec. 22, p. 16 and 23)]

Period	Precipitation (inches)	Temperature (°F; 20 record days)
January	1.36	25.5
February	1.46	29.1
March	2.02	36.8
April	1.76	44.4
May	1.26	51.5
June	.81	61.2
July	1.91	66.2
August	2.01	65.0
September	1.55	57.6
October	1.55	47.3
November	1.14	37.9
December	1.21	26.5
Annual average	18.04	45.8

Sagebrush, juniper, and piñon grow on the plains north of McElmo Canyon, and sparse grass, juniper, and piñon grow on the plains west of the mountains. The plains south and east of the Ute Mountains have only sparse grass, sage, and thistle. Lower slopes surrounding the mountains are covered moderately with juniper, piñon, and shrubs. Most of the middle-level slopes in the mountains proper are covered with oak brush, juniper, and piñon. Pine and fir grow on the upper slopes and ridges, and small clumps of aspen grow on the north slopes of Horse Mountain, Black Mountain, and Ute Peak.

The vegetation in the Ute Mountains is similar to that in the Henry Mountains of Utah described in considerable detail by Hunt, Averitt, and Miller (1953, p. 27–35).

PURPOSE AND SCOPE OF INVESTIGATION

The Ute Mountains of southwestern Colorado were mapped by the U.S. Geological Survey as part of the program of uranium investigations undertaken by the Survey on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission. The objectives of the work were: to determine the uranium resources and potentialities of the area; to provide detailed information on the relations of uranium ore deposits in the sedimentary rocks of the area to the igneous rocks of the Ute Mountains; and to fill a gap in the modern geologic map of the Colorado Plateau.

PREVIOUS WORK

The Ute Mountains were first described by Holmes, of the Hayden Survey (1877, p. 236–237), who referred to them as the El Late Mountains. Cross (1894, p. 211–214) reviewed Holmes' work and described the igneous rocks sampled by Holmes. Two of these samples were analyzed chemically and the analyses are reproduced in this report. Coffin (1920) mapped the structure and stratigraphy of McElmo dome. P. H. Metzger (written commun., 1944) studied the geology of the McElmo Canyon area, with emphasis on the Morrison Formation. Cadigan studied the Junction Creek Sandstone in McElmo Canyon in 1949.[1] In the spring of 1952, diamond-drill exploration of radioactive areas along faults in McElmo Canyon was undertaken by the Atomic Energy Commission. Geologic logs of the diamond-drill core are on file in the office of the Atomic Energy Commission in Grand Junction, Colo.

The Ute Mountains and the McElmo Canyon area were mapped in reconnaissance by E. M. Shoemaker and W. L. Newman during a succession of brief visits in 1951, 1952, and 1953. Shoemaker and Newman (1953) noted approximately 30 major laccoliths, and they concluded that the laccoliths had been fed laterally from two stocks—Black Mountain and Hermano Peaks ("The Knees"). They noted that most of the large dikes and the two stocks lie in a north-south zone, and suggested that the orientation indicated control of intrusion by a deep-seated structure in the basement complex. Geochemical studies by Shoemaker and Newman (written commun., 1955) suggested that the igneous rocks in the Ute Mountains may have been a source for the vanadium and uranium found in some of the faults and sedimentary beds of the McElmo Canyon area.

FIELDWORK AND ACKNOWLEDGMENTS

The Ute Mountains and the adjacent McElmo Canyon area were mapped during the spring and summer of 1955 and the summer of 1956. The geology was mapped on aerial photographs furnished by the U.S. Geological Survey and by the Soil Conservation Service of the Department of Agriculture. Base maps for the area were prepared from aerial photographs by the use of the Kelsh plotter and a radial planimetric plotter and slotted templates. Geology and planimetry were transferred simultaneously from the photographs to the base maps at a scale of 1:20,000. Horizontal and vertical control was established by setting up a triangulation net tied to the primary triangulation station "Ute" and to Coast and Geodetic Survey leveling lines in McElmo Canyon and Montezuma Valley. Approximately six stations were placed in each of the five 7½-minute quadrangles mapped. Clyde Duren, Jr., and Lloyd L. Smith, formerly of the U.S. Geological Survey, established many of the stations, and their assistance and advice are gratefully acknowledged.

Geologic maps of the five 7½-minute quadrangles on planimetric bases have been published in the U.S. Geological Survey Mineral Investigations Field Studies Map series (Ekren and Houser, 1957, 1959b, c, d; Houser and Ekren, 1959). Topographic maps of the Ute Mountains area were published by the Geological Survey late in 1957. The geologic map accompanying this report was prepared by reducing the original planimetric-geologic maps to 1:48,000 scale and transferring the geology to the new topographic base.

GEOLOGIC SETTING

The Ute Mountains are in the western Colorado margin of the Canyon Lands section of the Colorado Plateau (Fenneman, 1931, p. 307). The mountains rise above the Great Sage Plain, a broad expanse cut by deep, steep-sided canyons that extends northward from the Ute Mountains to the La Sal Mountains. The plain is formed mainly on gently dipping resistant sandstone of the Upper Cretaceous Dakota Sandstone. The broad Mesa Verde (Fenneman, 1931, p. 308–309) begins 6 miles east of the Ute Mountains and extends 20 miles eastward beyond the Mancos River. West and south of the Ute Mountains is the rugged canyon country of the San Juan River drainage.

The Ute Mountains area is on a structural terrace or bench between Blanding basin to the west-northwest and San Juan basin to the southeast. The laccolithic mountains lie on a structural dome formed by injection of

[1] Cadigan, R. A. 1952, The correlation of the Jurassic, Bluff, and Junction Creek sandstones in southeastern Utah and southwestern Colorado: Pennsylvania State College master's thesis.

magma and are just south of McElmo dome, a large star-shaped structure that probably originated as a result of basement uplift, igneous intrusion, and, possibly, movement of salt. To the southwest is the Defiance uplift and to the northeast, the San Juan uplift (Luedke and Shoemaker, 1952; Kelley, 1955).

Within a radius of 150 miles from the Ute Mountains are seven other laccolithic mountain groups: the La Plata and Rico Mountains to the east, the Carrizo Mountains to the south, the Henry and the Abajo Mountains to the northwest, the La Sal Mountains to the north-northwest, and the West Elk Mountains to the north-east. The igneous rocks in these laccolithic mountains are quite similar. Geologists who have studied the Colorado Plateau generally agree that the rocks are related and that most of the laccolithic groups were formed during the same geologic period. On the basis of geomorphic evidence, the laccolithic intrusive rocks and related structures are believed by Hunt (1956, p. 45) to be of late Miocene or early Pliocene age. Shoemaker (1956, p. 162), on the basis of stratigraphic evidence discussed on page 27, concluded that the intrusions took place near the end of the Cretaceous Period.

STRATIGRAPHY OF THE SEDIMENTARY ROCKS

The sedimentary rocks exposed in the Ute Mountains area are listed in table 2. Except for the surficial deposits, these rocks range in age from Triassic(?) and Jurassic (Navajo Sandstone) to Late Cretaceous (Point Lookout Sandstone). Tertiary and Cretaceous rocks younger than the lowermost beds of the Point Lookout Sandstone have been removed by erosion.

The thickness of Upper Cretaceous and Tertiary sedimentary rocks that once overlay the Ute Mountains area cannot be accurately determined. The lithology of the thick post-Point Lookout, pre-Animas sedimentary rocks of Late Cretaceous age that crop out a few miles southeast of the Ute Mountains indicates that the Ute Mountains area was not a topographic high during those periods of deposition. These sediments reflect

TABLE 2.—*Sedimentary rocks exposed in the Ute Mountains area, Colorado*

System and Series	Group	Formation and member	Character	Thickness (feet)	Economic value
Quaternary			Alluvium, 3 to about 75 ft thick; composed of interbedded mud, sand and gravel in valley fill and stream deposits; windblown sand and silt; talus; landslide deposits; block rubble; stream terrace gravel; pediment gravel; fanglomerate.	0–75	Fanglomerate gravel in McElmo Canyon and pediment gravel on eastern slopes of Ute Mountains are used in highway construction.
	Unconformity				
Upper Cretaceous	Mesaverde Group	Point Lookout Sandstone	Thin-bedded yellowish-gray and buff fine-grained sandstone interbedded with gray sandy shale.	200 (incomplete)	No recognized economic value in Ute Mountains area.
Upper Cretaceous		Mancos Shale; Juana Lopez Member	Predominantly gray to black shaly mudstone and claystone. The Juana Lopez Member is cuesta-forming sandy fossiliferous limestone and shale 25 to 100 ft thick, 475 ft above base of formation.	1,800–1,900	Some of the claystone has ceramic value for making brick and tile.
Upper Cretaceous		Dakota Sandstone	Yellowish lenticular sandstone and conglomeratic sandstone interbedded with carbonaceous shale and coal. Coal beds are extremely lenticular and usually contain considerable amounts of mud and silt.	110–140	Coal, ground water.
	Disconformity				
Lower Cretaceous		Burro Canyon Formation; Karla Kay Conglomerate Member	White, gray, and brownish sandstone and conglomerate interbedded with nonbentonitic green and red mudstone. Includes the Karla Kay Conglomerate Member in McElmo Canyon.	30–200	Karla Kay Conglomerate Member is uranium bearing in McElmo Canyon area.
Upper Jurassic	Morrison Formation	Brushy Basin Shale Member	Varicolored bentonitic mudstone and a few conglomeratic sandstone lenses.	150–300	Westwater Canyon and Salt Wash Members are uranium bearing in many parts of the Colorado Plateau. No uranium deposits are known in these members in the Ute Mountains area.
Upper Jurassic	Morrison Formation	Westwater Canyon Sandstone Member	Pale yellow-brown fine- to medium-grained sandstone interbedded with green bentonitic mudstone.	75–200	
Upper Jurassic	Morrison Formation	Recapture Shale Member	Tan and reddish-gray fine- to medium-grained sandstone interbedded with red mudstone.	0–200	
Upper Jurassic	Morrison Formation	Salt Wash Sandstone Member	Pale-brown fine- to medium-grained sandstone interbedded with predominantly red-brown mudstone.	0–200	
Upper Jurassic	San Rafael Group	Junction Creek Sandstone	Predominantly pink fine- to coarse-grained, poorly sorted sandstone, cross-stratified at high angle; weathers to a "slick rim." Correlates with the Bluff Sandstone of Utah and Arizona.	250–300	Ground water.
Upper Jurassic	San Rafael Group	Summerville Formation	Flat- and thin-bedded argillaceous sandstone and siltstone, brick red. Includes a 20-ft fine-grained well-sorted ledge-forming sandstone at top. Except for this unit, the formation is slope forming.	120–130	Upper sandstone unit is uranium bearing in McElmo Canyon. No mineral value—1958.
Upper Jurassic	San Rafael Group	Entrada Sandstone	Slick Rock Member, 70 to 80 ft thick, is sandstone that is pale brown and light pink at top and that grades to white and finally to orange red in lower part, weathers to a "slick rim." Dewey Bridge Member is very fine grained brick-red argillaceous sandstone, 25 to 35 ft thick.	100–115	Ground water.
Jurassic and Triassic(?)	Glen Canyon Group	Navajo Sandstone	Predominantly orange fine-grained eolian sandstone.	300	Ground water.

marine or marginal marine conditions, show no lateral change in the proximity of the Ute Mountains, and undoubtedly were once continuous over the Ute Mountains. The lower part of the Animas Formation (McDermott Member), however, contains abundant andesite detritus, and the Ute Mountains may have been uplifted first during McDermott time (Shoemaker, 1956, p. 162). The post-Animas (early Tertiary) sediments that crop out a few tens of miles southeast of the Ute Mountains are largely fluviatile in origin. Present knowledge of these early Tertiary sediments is inadequate to determine whether the Ute Mountains area was supplying or receiving sediments.

PRE-NAVAJO ROCKS

In the Ute Mountains area, the sedimentary rocks that underlie the Navajo Sandstone according to Zabel (1955, p. 132–135) are in descending order: the Upper Triassic(?) Kayenta Formation, Wingate Sandstone, the Upper Triassic Chinle Formation (includes Shinarump Member), the Lower and Middle(?) Triassic Moenkopi Formation, the Permian Cutler Formation, the Pennsylvanian and Permian(?) Rico Formation, the Middle Pennsylvanian Pinkerton Trail Formation of Wengerd and Strikland (1954) and the Hermosa Formation (includes Paradox Member), the Mississippian Leadville Limestone, the Upper Devonian Ouray Limestone and Elbert Formation, and equivalents of the Middle Cambrian Ophir Formation and Lower Cambrian Tintic Quartzite of northern Utah.

Several of these formations are of economic interest in the Ute Mountains area. The Paradox Member of the Hermosa Formation produces oil and gas in the nearby Aneth field of Utah and is a potential producer in the Ute Mountains area; the Leadville in the McElmo dome produces carbon dioxide gas, and in McElmo Canyon the Shinarump Member produces flammable gas.

The nearest exposures of Triassic and uppermost Paleozoic rocks are in the Dolores River Canyon near Dolores, Colo., in the La Plata Mountains, Colo., and along the San Juan River in Utah. The rocks in the La Plata Mountains were described in detail by Eckel (1949, p. 8–24). Rocks older than the Hermosa Formation of Pennsylvanian age crop out north of Durango, Colo., along the Animas River valley in the vicinity of the Needle Mountains (Cross and Hole, 1910).

TRIASSIC(?) AND JURASSIC

GLEN CANYON GROUP

NAVAJO SANDSTONE

The Glen Canyon Group includes the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone. The Navajo Sandstone is the only formation in the Glen Canyon Group that is exposed in the Ute Mountain area.

The Navajo Sandstone (Gregory, 1917, p. 57–59) crops out along the south flank of McElmo dome in McElmo Canyon. A thickness of about 300 feet is exposed along Sand Creek, a tributary of McElmo Creek, in sec. 26, T. 36 N., R. 18 W. The base of the formation is not exposed in Sand Creek, but a gamma-ray log of the National Oil and Gas Co.'s West 1, located a few miles east of Sand Creek, indicates a total thickness of 300 feet for the Navajo Sandstone. This thickness suggests that the Navajo-Kayenta contact can be no more than a few feet below the bed of Sand Creek.

Throughout the McElmo Canyon area the Navajo Sandstone is predominantly orange and fine grained, and is composed of subangular clear quartz grains. "Berries" of medium-grained well-rounded quartz are common. In general, the Navajo is thick bedded and is alternately cross-stratified and flat stratified. The cross-stratified beds are thickest and are separated from flat-stratified beds by planar erosion surfaces that form distinct horizontal partings in the weathered outcrop (fig. 2). The sequence of cross-stratified beds horizontally truncated at many intervals suggests eolian deposition alternating with subaqueous deposition.

That water played a role in the deposition of the Navajo Sandstone is also indicated by the occurrence of a bed of dense gray limestone about 4 feet thick near the top of the formation that crops out in the northern part of McElmo Canyon. The limestone is nonfossiliferous and was probably deposited in a fresh-water lake.

The following section was measured on the east side of Sand Creek Canyon in sec. 26, T. 36 N., R. 18 W., by V. L. Freeman and L. C. Craig of the U.S. Geological Survey; minor changes have been made in this section as recorded to conform with the nomenclature used in this report. In this report, rock color terms that are followed by color symbols are from the National Research Council "Rock-color Chart" (Goddard and others, 1948).

1. *Lower McElmo Canyon section (pl. 1)*

	Feet
Entrada Sandstone.	
Navajo Sandstone:	
Sandstone, very pale orange; some pale reddish-brown areas; fine-grained; large-scale cross laminations; forms a bench	80.2
Sandstone, red to yellow, very fine grained, very angular; contains some disseminated coarse grains ("berries")	1.2
Sandstone, pinkish-gray, medium fine-grained; some larger angular grains; cross laminated	7.6
Sandstone, pinkish-gray, medium fine-grained; contains some larger angular grains; cross laminated	1.9

1. *Lower McElmo Canyon section (pl. 1)*—Continued

Navajo Sandstone—Continued	Feet
Sandstone, pink and white, fine-grained, subangular, thin-bedded, cross laminated	15.7
Sandstone, silty, yellowish-gray; some dark-red patches; very fine grained; cross laminated	23.8
Sandstone; pale reddish orange to very pale orange at top; very fine grained, subangular; massive cross-laminated unit	44.2
Sandstone; pale red at base to very pale orange at top; fine-grained, subrounded; massive cross-laminated unit	21.9
Sandstone; light-brown, fine-grained, subrounded; contains some black accessory mineral grains; calcareous; wedging cross lamination	2.8
Sandstone, pale reddish-brown (10*R* 6/4), fine-grained, subangular; contains very minor accessory minerals; calcareous; wedging cross lamination	18.5
Sandstone, pale reddish-brown (10*R* 6/4), fine to very fine grained, subangular, calcareous	38.3
Sandstone, light-brown, fine-grained, subrounded, calcareous, cross-laminated	8.5
Sandstone, moderate reddish-orange to pale reddish-brown, fine-grained; subangular at base to very fine grained at top; contains scattered black accessory mineral grains; calcareous; massive with broad cross lamination; base of exposure	43.0
Total (incomplete?) Navajo Sandstone	307.6

Baker, Dane, and Reeside (1936, p. 44) regarded the Navajo Sandstone as a large northeastward-thinning wedge of eolian sand. The Ute Mountains area apparently is very close to the eastern edge of the wedge, for the Navajo pinches out between McElmo Canyon and the La Plata Mountains.

No fossils were found in the Navajo Sandstone in the Ute Mountains area. A fossil vertebrate found in the Navajo Sandstone of northeastern Arizona was described by Camp and Vanderhoof (1935, p. 385) as "a small dinosaur about the size of a turkey." Camp (1936, p. 39) named it *Segisaurus halli* and stated (1936, p. 52): "It represents a single member of an unknown upland fauna and despite its primitive characters it could be placed in either the Triassic or Jurassic." Harshbarger and others (1957, p. 22–31) described findings of other organic remains from the Navajo Sandstone, but none of these are diagnostic of age. The assignment of Triassic(?) and Jurassic age for the Navajo Sandstone is based on a variety of evidence summarized by Lewis and others (1961) who point out that the age of the Navajo must be based upon: (a) the age of the Kayenta Formation, which intertongues with the lower part of the Navajo, and (b) the age of the fossiliferous Carmel Formation, which intertongues with the upper part of the Navajo.

The contact of the Navajo Sandstone with the overlying Entrada Sandstone is sharp in the McElmo Canyon area.

JURASSIC SYSTEM

SAN RAFAEL GROUP

ENTRADA SANDSTONE

The San Rafael Group in McElmo Canyon includes the Entrada Sandstone, Summerville Formation, and the Junction Creek Sandstone. These formations are of Late Jurassic age and are about 1,000 feet thick. The local nature of the exposures of the San Rafael Group in the Ute Mountains area precludes a discussion of sedimentary history other than the brief statements included with the lithologic discussion. A synthesis based on a regional study was made by Harshbarger and others (1957, p. 23–51).

The Entrada Sandstone (Gilluly and Reeside, 1928, p. 76) consists of two units in McElmo Canyon and its tributaries. The two units have been named the Dewey Bridge Member and the Slick Rock Member by Wright, Shawe, and Lohman (1962, p. 2057). The type locality of the Dewey Bridge Member is at Dewey Bridge, Grand County, Utah, and the type locality of the Slick Rock Member is at Slick Rock, San Miguel County, Colo., about 30 miles north of the Ute Mountains area. The Dewey Bridge Member (lower unit) is red hoodoo-weathering sandstone that forms a bench over the resistant Navajo Sandstone. The Dewey Bridge Member formerly was thought to correlate with the Carmel Formation. The upper unit of the Entrada, the Slick Rock Member, is white to orange clean sandstone that weathers to a nearly vertical rounded cliff or "slickrim."

The two sandstone units are conspicuous in the McElmo Canyon area. (See fig. 2.) The Dewey Bridge Member, which is 25 to 35 feet thick, is composed of brick-red argillaceous and silty, very fine grained sandstone. The Slick Rock Member is 70 to 80 feet thick; it is orange to light pink in the lower part and grades to white and pale brown in the upper part. It is fine grained, is composed of subangular clear quartz and abundant well-rounded medium to medium-coarse quartz "berries," and is cross-stratified at medium angles. The cross-strata commonly are truncated by planar surfaces of erosion that underlie horizontal laminae. The Slick Rock Member includes a 6-foot thick ledge at the top that may correspond to the lower part of the Bilk Creek Sandstone Member of the Wanakah Formation.

The following section was measured in Sand Creek Canyon in sec. 26, T. 36 N., R. 18 W., by Ekren.

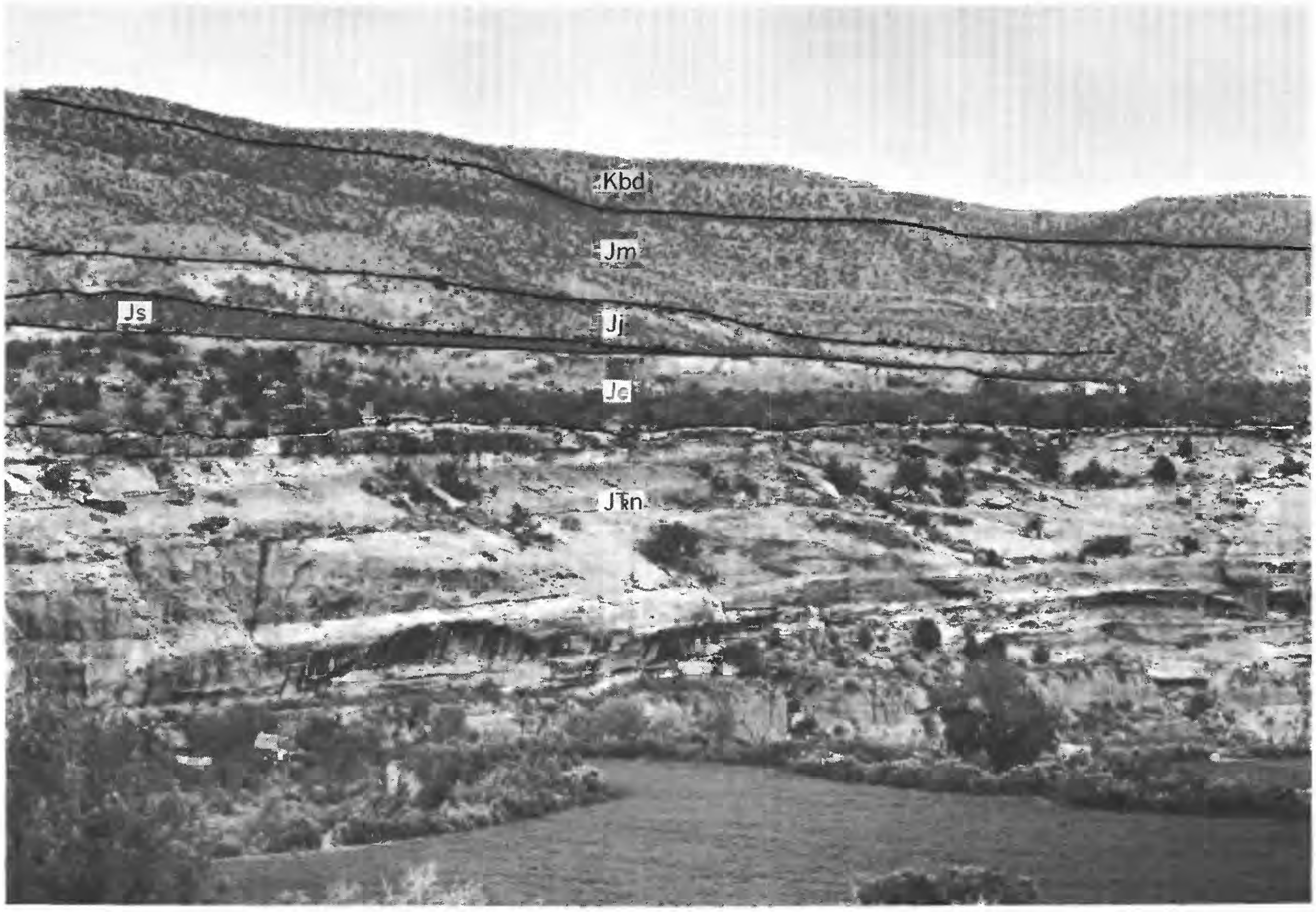


FIGURE 2.—Navajo Sandstone (JƗn) in McElmo Canyon. Note horizontal partings in upper 200 feet. Bench above Navajo is formed in silty sandstone facies of the Dewey Bridge Member of the Entrada. Slick Rock Member of the Entrada (Je) is above bench. The Summerville Formation (Js), the Junction Creek Sandstone (Jj), the Morrison (Jm), and the Burro Canyon and Dakota (Kbd) occupy slope in the background.

2A. *Sand Creek section (pl. 1)*

	Feet
Summerville Formation.	
Entrada Sandstone:	
Slick Rock Member:	
Sandstone, pale-brown to light yellow-brown, fine-grained, poorly sorted; contains abundant medium to medium-coarse clear quartz grains ("Entrada berries"); sandstone is limonite-flecked and mottled; unit forms ledge ("non-slick-rim" weathering)	6
Sandstone; light-pink at base grading to white and to pale-brown at top; weathers to very pale brown and white; very fine to fine grained; well-rounded quartz grains or "berries" fairly common in light-pink zone, rare in white zone, common in pale-brown zone near top. Light-pink zone is abundantly freckled with limonite; entire unit is "slick-rim" weathering and is cross-stratified at medium angle. Cross strata are bounded by horizontal partings	48
Sandstone, orange-red; weathering orange to red; very fine grained, grains angular to subangular; bedding obscure, massive; "slick-rim" weathering; calcite cement	20

2A. *Sand Creek section (pl. 1)*—Continued

	Feet
Entrada Sandstone—Continued	
Slick Rock Member—Continued	
Sandstone, light-tan, buff; weathering composed of very fine quartz grains and a few medium-coarse grains of well-rounded clear quartz "berries"; the very fine grains subangular to subrounded; unit resistant (abundant calcareous cement), does not weather "slick" as unit above does; base sharp	2
Dewey Bridge Member:	
Sandstone, argillaceous; very fine to silt-sized grains, brick red; hoodoo weathering. Upper 10 ft well exposed, lower part (about 15 ft) poorly exposed and mantles bench formed on top of resistant Navajo Sandstone	30
Total Entrada Sandstone	106

The thickness and lithology of the Entrada Sandstone show little variation throughout the McElmo Canyon area. The following section was measured in Goodman Canyon approximately 3 miles east of Sand Creek Canyon, by L. C. Craig, V. L. Freeman, and J. D. Strobell, Jr.

3. Upper McElmo Canyon section (composite) (pl. 1)

Summerville Formation.	
Entrada Sandstone:	
Slick Rock Member:	*Feet*
Sandstone; very pale orange (10*YR* 8/2) in upper half, pinkish cast in lower half; fine grained; contains disseminated medium-fine, rounded to well-rounded grains or "berries"; composed of subangular clear quartz and colored minor accessory minerals; structureless; lower half forms reentrant	5.6
Section A. Measured on north side of McElmo Canyon just east of old oil rig and west of mouth of Goodman Canyon. Sec. 30, T. 36 N., R. 17 W.	
Sandstone, white, pale yellow weathering; predominantly fine grained; rare medium-sized grains; composition same as unit below; unit forms massive rounded top to "slick rim"; poorly formed irregular horizontal bedding	8.6
Sandstone, white, predominantly fine grained; composition same as unit below; noncalcareous; unit predominantly horizontally laminated but a few beds show fine-scale cross lamination	12.1
Sandstone, white, fine- to medium coarse-grained; composed of subangular to well-rounded clear quartz and very minor black, gray, and pink accessory minerals; cross laminated; medium scale (3 to 4 ft) wedge-bedding	15.4
Sandstone, white to pale-yellow, very fine grained; composition same as unit below; horizontally laminated; unit forms a reentrant	4.0
Sandstone, white to pale-yellow, fine- to medium-grained; composed of subangular to rounded clear quartz and minor green and black accessory minerals; highly cross laminated; wedge bedded at a fine to medium scale. Top contact sharp and beveled; forms spring line	4.2
Sandstone; moderate reddish orange in lower half and white to pale yellow in upper half; very fine to fine grained; composed of subangular to subrounded clear quartz and black, gray, green, and pink accessory minerals; slightly wavy horizontal laminations; weathers massive and rounded; color contact ranges from sharp to vague and irregular; orange sandstone slightly calcareous, white is highly calcareous	9.2
Sandstone, moderate reddish-orange (10*R* 6/6), fine to very fine grained; composed of subangular clear quartz and disseminated medium-coarse "berries"; massive and structureless in lower 15 ft; discontinuous clayey laminae in upper 4 ft indicate horizontal bedding	18.8
Sandstone, grayish-orange-pink (10*R* 8/2) to moderate reddish-orange, very fine to medium fine-grained, poorly sorted; contains subangular to rounded clear quartz, medium-coarse "berries" of well-rounded frosted quartz, and white to light- and dark-gray chert; cross laminated, wedge bedded at a fine scale (6 in to 2 ft)	4.5

3. Upper McElmo Canyon section (composite) (pl. 1)—Con.

Entrada Sandstone—Continued	
Dewey Bridge Member:	*Feet*
Top contact gently undulant with sharp lithic change	---
Sandstone, pale reddish-brown (10*R* 5/4) and moderate reddish-orange (10*R* 6/6), very fine to fine-grained; composed of subangular clear quartz and minor accessory minerals; color and weathering controlled by degree of irregular discontinuous dark clayey lamination; weathers shaly to earthy and locally forms rounded biscuit-shaped cliffs	18.1
Sandstone, moderate reddish-orange (10*R* 6/6) to moderate orange-pink (10*R* 7/4), fine-grained; contains subangular clear quartz, pink and black accessory minerals; contains numerous layers with concentrations of medium-grained well-rounded frosted quartz "berries"; platy bedded	2.3
Total Entrada Sandstone	102.8

Stratification in the Dewey Bridge Member (red silty facies) in the McElmo Canyon area is inconspicuous Most of the visible stratification is flat. The sparseness of cross-stratification of either eolian or fluviatile type together with fair sorting of the grains suggests deposition in a lacustrine or marine environment.

The most conspicuous feature of the stratification of the Slick Rock Member of the Entrada Sandstone of the McElmo Canyon area is the large number of horizontal (planar) surfaces of erosion that are continuous over long distances. These surfaces commonly separate wedge-stratified beds from horizontal laminae. The alternating stratification suggests subaqueous and subaerial deposition.

Several alcoves have been weathered into the Slick Rock Member of the Entrada Sandstone in the McElmo Canyon area. These alcoves were used by ancient Indians as building sites for cliff houses. The cliff houses are most numerous and are best preserved in the Sand Creek area.

The contact of the Slick Rock Member with the overlying siltstones and mudstones of the Summerville Formation is sharp in McElmo Canyon, but beds of sandstone similar to those in the Entrada occur in the lower part of the Summerville Formation, and the two formations may intertongue.

SUMMERVILLE FORMATION

The Summerville Formation of Late Jurassic age was named by Gilluly and Reeside (1928, p. 80) from exposures on Summerville Point in the San Rafael Swell, Utah. In the type locality the Summerville overlies the Curtis Formation.

In the McElmo Canyon area the Summerville Formation overlies the Entrada Sandstone and underlies the Junction Creek Sandstone. The formation is dominantly brick red to red brown and is composed of alternating and gradational beds of very fine to fine-grained well-sorted sandstone and silty mudstone. Stratification is generally flat. The formation is from 125 to 150 feet thick and, with the exception of a resistant sandstone bed 10 feet below the top, is bench forming. The lower 10 to 15 feet of the formation contains thin beds of white to pale-brown sandstone that resemble the Entrada Sandstone.

The following section was measured by Ekren in Sand Creek Canyon, sec. 24, T. 36 N., R. 18 W.

2B. *Sand Creek section (pl. 1)*

	Feet
Junction Creek Sandstone.	
Summerville Formation:	
Mudstone, red-brown	5
Sandstone, pale-brown, fine-grained	1
Sandstone, red-brown, very soft, fine-grained; contains abundant red-brown hematite or limonite	3
Mudstone, red-brown	1
Sandstone, white to pale-green, light-green-weathering, fine-grained, well-cemented; protects softer sandstone units below	4
Sandstone, red-brown to chocolate-brown, fine-grained, soft and friable; abundant hematite	4
Sandstone, light-red to light-gray, soft, limonite-flecked, flat-bedded, massive-weathering	9
Siltstone, red, hard, spheroidal-weathering	3
Sandstone, light-red, very fine grained; this unit, and the overlying sandstone and siltstone units form a ledge	10
Sandstone, light-red to white, very fine to fine-grained, very soft; bedding obscure; bench forming	14
Siltstone, argillaceous, gray-green and light-red	2
Sandstone, pale-yellow to pink; fine to very fine quartz grains; limonite flecked and blotched with unknown black mineral; contains sparse black opaque minerals; flat-bedded	8
Mudstone, red	2
Sandstone, tight, hard, flat-bedded; contains very fine grained quartz	2
Sandstone and mudstone, light-red and brick-red, alternating and gradational, flat-bedded; sandstone is very fine grained	8
Mudstone, brick-red; a few thin layers of very fine grained sandstone usually less than 1 ft thick that are light red to pink, dark red weathering; unit is flat bedded	37
Sandstone, white buff-weathering; very fine grained quartz "berries"; rock is tight and hard, calcareous cemented; unit splotched and flecked with limonite	2
Siltstone and mudstone, brick-red; forms brick-red soil; bench forming. Layer of fine-grained sandstone 2.5 ft thick crops out about 6 ft above base of unit; this sandstone is light brown to pale brown, hard with calcareous cement, spotted with limonite, and together with unit above probably corresponds to the Bilk Creek Member (Goldman and Spencer, 1941)	12
Total Summerville Formation	127

The resistant sandstone near the top of the Summerville is continuous throughout the McElmo Canyon area. This sandstone is generally reddish brown or pink, but near igneous intrusive rocks in the Ute Mountains and near some faults in McElmo Canyon it is yellow brown. It is radioactive near faults in the vicinity of Rock Creek in secs. 22 and 23, T. 36 N., R. 18 W.

L. C. Craig, J. D. Strobell, Jr., and V. L. Freeman measured the Summerville Formation on the west side of Goodman Canyon about 1¼ miles north of the fruit farm at the mouth of the canyon in sec. 29, T. 39 N., R. 17 W.

3. *Upper McElmo Canyon section (pl. 1)*

	Feet
Junction Creek Sandstone.	
Summerville Formation:	
Claystone and sandstone, grayish-red (10*R* 4/2). Claystone is fine grained to medium grained, sandy, shaly to earthy weathering. Sandstone is white, medium fine to fine grained, noncalcareous; accessory minerals as in unit below; forms several beds as much as 1 ft thick	16.2
Sandstone, grayish orange-pink (10*R* 8/2) to white, medium fine- to fine-grained; composed of rounded clear quartz and minor amber, pink, and black accessory minerals; forms fairly resistant ledge	4.3
Sandstone, clayey, dark reddish-brown (10*R* 3/4), very fine grained; composed of subangular clear quartz; earthy to shaly weathering; forms small bench	3.1
Sandstone, grayish orange-pink (10*R* 8/2) to white, medium fine- to fine-grained; composed of rounded clear quartz and minor amber, pink, and black accessory minerals; predominantly wavy lamination; forms prominent ledge	15.8
Sandstone, light grayish-red (10*R* 5/2) to white, nonclayey; weathers rounded; structureless or showing wavy lamination and thin shaly partings	9.8
Sandstone, moderate orange-pink (10*R* 7/4) to white, finely mottled, medium fine- to fine-grained; some medium-sized grains; coarser grains well-rounded, finer grains subangular; rock slightly calcareous; weathers, soft, friable; indistinct bedding, 60 percent cross-laminated at fine to medium scale, 40 percent horizontally laminated; several prominent horizontal bedding planes	24.4
Sandstone, clayey, dark-red, mottled light-green, very fine grained, noncalcareous; weathers rounded to shaly and earthy	2.2
Sandstone, white, dark-brown weathering; predominantly fine grained; clear quartz and red, pink, green, yellow, and black accessory minerals; wavy laminated and cross laminated on a fine scale; forms prominent ledge; sand typical of Summerville	2.6
Sandstone and claystone interbedded. Sandstone is pale reddish brown (10*R* 5/4), silt sized to medium fine-grained sand size; weathers to shaly irregular to rounded ledges. Claystone is dark red, very sandy, earthy weathering; contains disseminated sand grains. Two ledges of white brown-weathering, very fine grained to fine-grained resistant non-	

3. *Upper McElmo Canyon section (pl. 1)*—Continued

	Feet
Summerville Formation—Continued	
calcareous sandstone between 29 and 34 ft above base of unit	59.1
Sandstone; mottled very pale orange and pale-red; predominantly fine grained; composed of subangular clear quartz and colored accessory minerals; contains disseminated rounded medium fine-grained "berries"; forms prominent ledge	1.9
Sandstone and claystone. Sandstone is pale red (5*R* 6/2), very fine to medium fine grained; forms several ledges as much as 1 ft thick. Claystone is dark red, very sandy, nonresistant, earthy weathering	9.7
Total Summerville Formation	149.1

The flat stratification and good sorting of grains in the Summerville Formation indicate deposition in clear water. The gradual increase in sand content upward in the formation suggests deposition in a receding sea.

The contact of the Summerville Formation with the overlying Junction Creek Sandstone is gradational throughout the McElmo Canyon area. Sandstone and mudstone of the Summerville Formation are interbedded with sandstone similar to that of the overlying Junction Creek in many places. The contact was chosen where rocks lithologically similar to the Junction Creek predominate above and rocks lithologically similar to the Summerville predominate below.

JUNCTION CREEK SANDSTONE

The Junction Creek Sandstone was named by Goldman and Spencer (1941, p. 1750–1751) from an exposure between Junction Creek and the Animas River a few miles north of Durango, Colo. It correlates with the Bluff Sandstone of Utah, Arizona, and New Mexico.

In the McElmo Canyon area the Junction Creek Sandstone forms a conspicuous cliff, characteristically a "slick rim," and its outcrops closely resemble those of the Entrada Sandstone. Generally, however, the Junction Creek Sandstone is light red, reddish orange, or pink, in contrast with the white to orange Entrada Sandstone. In the vicinity of igneous intrusions, the Junction Creek Sandstone is light brown. The formation averages about 280 feet in thickness and is divisible into three gradational units based on the type of bedding. The lower unit, 30 to 50 feet thick, is composed of alternating beds of flat-stratified and cross-stratified sandstone. The cross-strata dip at low angles and are truncated by planar surfaces of erosion. A few of the horizontal surfaces of erosion may be continuous across all the exposures in McElmo Canyon. The middle unit, 150 to 250 feet thick, is composed of thick-bedded fine- to coarse-grained sandstone that is cross-stratified at high angles (nearly 30° in several exposures). The upper unit, 20 to 50 feet thick, is argillaceous fine-grained reddish sandstone, commonly mottled or blotched green and gray. This unit has obscure flat stratification and weathers to hoodoos (fig. 3).

FIGURE 3.—Upper unit (Jj) of the Junction Creek Sandstone underlying the Salt Wash Member of the Morrison Formation (Jms). Unit weathers to hoodoos. Ute Peak, Mable Mountain, and North Black Mountain appear in the background. Photograph courtesy of R. A. Cadigan.

Subangular red and orange chert grains are common in the lower and middle units. The chert commonly is concentrated in single beds within a set of strata. The angular chert grains contrast with the subrounded to rounded quartz grains.

The following section was measured by Ekren on the east side of Sand Creek in sec. 24, T. 36 N., R. 18 W.

2B. *Sand Creek section (pl. 1)*

	Feet
Salt Wash Member of the Morrison Formation.	
Junction Creek Sandstone:	
Upper unit:	
Sandstone, argillaceous, light-red; weathers to red with pink, green, and gray blotching; obscure flat bedding; weathers to massive hoodoos; contains very fine grained quartz	30
Middle unit:	
Sandstone, pink in variegated hues; weathers darker pink to red brown; "slick-rim" weathering; contains fine- to medium fine-grained pink-coated quartz grains, minor fine-grained variegated chert, cross-stratified (strata near top dip 30°); joints or fractures very sparse; rock poorly cemented; base gradational	85
Sandstone, pink to orange; weathers darker pink to reddish orange; medium fine to medium grained, poorly sorted; calcareous cement; contains clear subrounded quartz and sparse medium- to coarse-grained subangular red, gray, and orange chert; cross-stratified at medium angles; "slick-rim" weathering; jointing conspicuous in upper part; joints "veined" as described in unit below. A conspicuous horizontal parting surface separates this unit from unit below	135

2B. *Sand Creek section* (*pl. 1*)—Continued

	Feet
Junction Creek Sandstone—Continued	
Lower unit:	
Sandstone, light-red to orange-pink; weathers dark coral; fine to medium grained at base becoming fine grained at top; alternating flat- and cross-stratified beds; cross-strata truncated by horizontal surfaces of erosion; sandstone is soft and friable. Near the base of this unit the sandstone contains more cement (calcareous?) and is greatly fractured; joints are vertical, horizontal, and at low angles, and are filled with sandstone that is well cemented with silica; filled joints protrude as "veins" from weathered sandstone surfaces; joints die out or become obscure in upper part of the unit	40
Total Junction Creek Sandstone	290

The Junction Creek Sandstone of southwestern Colorado has been correlated with the Bluff Sandstone of southeastern Utah by Cadigan (in Craig and Cadigan, 1958, p. 182–185). Cadigan divided the Junction Creek into four members on the basis of sedimentary structures. His basal member, "A," corresponds to the writers' lower unit; his "B" and "C" members correspond to the writers' middle unit; his "D" member to the upper unit.

The lithology of the lower unit of the Junction Creek Sandstone indicates alternating subaqueous and subaerial deposition, which in turn suggests an oscillating sea at the end of Summerville time. The middle unit reflects predominantly eolian deposition. Sand dunes 50 feet high were common during this period. The flat stratification of the upper unit may indicate a return of subaqueous conditions or deposition on a low flood plain near sea level.

The contact with the overlying Salt Wash Member of the Morrison Formation is locally disconformable. In many places lenses of fluviatile sandstone of the Salt Wash Member have been deposited in channels scoured in the Junction Creek Sandstone by streams that removed much, and in some places all, of the upper unit of the Junction Creek Sandstone. In other places the argillaceous sandstone of the upper unit grades into mudstone and siltstone typical of the Salt Wash.

The irregular Junction Creek-Salt Wash contact suggests that the earliest streams of Salt Wash time flowed with sufficient velocity over a Junction Creek surface of low relief to cause downcutting through the underlying soft muddy sands. In places, stream deposition of sand alternated with subaqueous (flood-plain?) deposition of argillaceous sand, mud, and silt.

MORRISON FORMATION

The Morrison Formation was named by Emmons, Cross, and Eldridge (1896) from the town of Morrison, near Denver, Colo., where the formation is about 200 feet thick and is composed of green or gray fresh-water marls and thin beds of limestone and sandstone.

Throughout the Colorado Plateau the Morrison Formation is composed of stream and flood-plain deposits. Sandstone and conglomeratic sandstone occur in ancient stream channels, and mudstone on contiguous flood plains. Fluviatile deposition prevailed during early Morrison time and gradually gave way to predominant flood-plain deposition during late Morrison time.

The Morrison of the Ute Mountains area has been divided into four members. These are, in ascending order: the Salt Wash Sandstone Member, Recapture Shale Member, Westwater Canyon Sandstone Member, and Brushy Basin Shale Member (Gilluly and Reeside, 1928; Gregory, 1938; and Lupton, 1914). A discussion of the regional aspects of the Morrison is given by Craig and others (1955, p. 134–159).

The lower three members—the Salt Wash, Recapture, and Westwater Canyon—are composed predominantly of lenticular light-tan and light-gray sandstone which is interstratified with thin red or green siltstone and claystone. The Brushy Basin, a bentonitic mudstone, is mainly green, but is subordinately red, purple, and gray.

Because the upper two members, and also the lower two, intertongue and intergrade to a considerable extent field division is arbitrary in many places. The Westwater Canyon Member intertongues with the Brushy Basin. The Westwater Canyon and the Recapture Members do not intertongue, but their distinction is extremely difficult and is based largely on the predominance of red mudstone in the Recapture in contrast to predominantly green mudstone in the Westwater Canyon. Where the Recapture is absent in eastern McElmo Canyon, the Westwater Canyon possibly intertongues with the upper lenses of the Salt Wash. The Salt Wash Member intertongues and intergrades with the Recapture to a considerable degree in most places.

The intertonguing and intergrading of members of the Morrison Formation in the Ute Mountains area are believed to reflect alternating deposition from two different source areas. Sediments forming the Recapture and Westwater Canyon Members were derived from an area south of Gallup, N. Mex. (Craig and others, 1955, p. 150). Sediments forming the Salt Wash and Brushy Basin probably were derived from a major source area in west-central Arizona and southeastern California. The lower three members of the Morrison in the Ute Mountains area show considerable blending of sediments from the two sources.

Despite the complexities of deposition during Morrison time and considerable variation in the thicknesses of the individual members, the total thickness of the Morrison is consistently between 500 and 650 feet. Where one member is thin, generally, another is correspondingly thick. The Brushy Basin Member and overlying Burro Canyon Formation have a similar nearly constant total thickness. This consistency in total thickness is of value in determining structure below the Morrison from data obtained on formations above the Burro Canyon.

The assignment of a Late Jurassic age to the Morrison in the Ute Mountains area is based on lithologic correlation with the Morrison of other parts of the Colorado Plateau where a Late Jurassic age seems indicated by vertebrate remains (Stokes, 1944).

SALT WASH SANDSTONE MEMBER

The name Salt Wash Sandstone Member was first proposed by Lupton (1914, p. 125–127) for a member of the McElmo Formation. The name McElmo Formation was later abandoned, and these rocks were divided into the Morrison, Summerville, Entrada, and Carmel formations; and the base of the Morrison was defined as the base of the Salt Wash (Baker and others, 1927; Gilluly and Reeside, 1928).

In the Ute Mountains area, the Salt Wash Member consists of interbedded sandstone and predominantly red mudstone. It lies upon massive crossbedded sandstone of the Junction Creek and is overlain by the Recapture, Westwater Canyon, or Brushy Basin Members. The sandstone lenses of Salt Wash range from white or light gray to pale yellow or very pale brown. They are trough cross-stratified and are composed of fine- to medium fine-grained clear subangular to subrounded quartz accompanied by sparse to common accessory grains of black, white, red, or pink color. The sandstone lenses are interbedded with dark-red, dark-purple, and red-brown mudstone. Gray or green-gray mudstone is extremely rare.

The Salt Wash Member is exposed continuously for a distance of about 11 miles along the slopes of McElmo Canyon. It is absent between the Junction Creek Sandstone and the Recapture Member on the structural dome just south of Sentinel Peak in the Sentinel Peak NE quadrangle, although some of the sandstone there mapped as the Westwater Canyon Member is lithologically similar to the Salt Wash of McElmo Canyon and may be a bed of the Salt Wash. The Salt Wash Member is absent also in northeastern Arizona, a few miles northwest of the Carrizo Mountains (L. C. Craig, oral commun., 1956).

The thickness of the Salt Wash Member varies considerably in McElmo Canyon. The member is 90 to 110 feet thick near the west end of the canyon, where it is overlain by the Recapture Member. Farther east, it is approximately 150 feet thick, and the Recapture Member is absent. Still farther east, at Trail Canyon, the Salt Wash is 200 to 250 feet thick and the overlying Westwater Canyon Member is thin.

The basal sandstone of the Salt Wash Member commonly is separated from the underlying Junction Creek Sandstone by red-brown mudstone 3 to 50 feet thick. Because this mudstone resembles the mudstone interlayered higher in the Salt Wash, it is included with the member. The contact of the Salt Wash with the overlying Recapture Member, and locally with the Westwater Canyon Member, is difficult to determine. In contrast to the Salt Wash, the sandstone beds of the Recapture and Westwater Canyon Members contain very sparse detrital grains of feldspar and generally are interbedded with red and green mudstones, respectively. The pink tone of the Recapture Shale Member is distinctive and contrasts with the colors of the Salt Wash and Westwater Canyon Members. In much of western McElmo Canyon the contact between the Salt Wash and the Recapture is marked by a narrow bench formed on the top of the uppermost part of the Salt Wash Sandstone Member. (See fig. 4.)

RECAPTURE SHALE MEMBER

The Recapture Shale Member was first named and described by Gregory (1938, p. 58) from Recapture Creek, southeastern Utah. In the Ute Mountains, it is composed of interbedded sandstone and mudstone. The sandstone beds are light gray, pinkish gray, or light brown on fresh surfaces and weather to pinkish gray or brownish gray. The quartz grains are fine grained, poorly sorted, and subangular to subrounded. Black, orange, pink, and white accessory grains are common. Detrital grains of feldspar are extremely sparse. The mudstone beds are pale red, reddish green, and pale green.

McElmo Canyon marks the approximate northern limit of the Recapture Member in southwest Colorado (Craig and others, 1955, p. 137–140). It is present west of a north-south line through the junction of Sand Creek with McElmo Creek. In the lower McElmo Canyon section measured by L. C. Craig (written commun., 1949), the Recapture is 117 feet thick. It is more than 260 feet thick south of the Ute Mountains where exposed in a breached dome south of Sentinel Peak. In this exposure the member contains more siltstone and claystone than in McElmo Canyon.

The intertonguing and intergrading relations of the Recapture with the overlying and underlying members have been discussed. The Recapture is recognized regionally in an oval-shaped area stretching from west of Santa Fe, N. Mex., into southeastern Utah. In that

FIGURE 4.—Salt Wash Sandstone Member (Jms), Recapture Shale Member (Jmr), and Westwater Canyon Sandstone Member (Jmw) of the Morrison Formation viewed northward from State Highway 32 near the Karla Kay mine. Upper hoodoo-weathering unit of the Junction Creek Sandstone (Jj) is barely visible in lower part of photograph. Note the topographic break at the top of the Salt Wash Sandstone Member.

area, it has been divided into three facies (Craig and others, 1955, p. 137–142): a conglomeratic sandstone facies, a sandstone facies, and a claystone and sandstone facies. The conglomeratic sandstone facies and the sandstone facies occupy the south-central part of the oval area. The Ute Mountains area is on the northeastern edge of the claystone and sandstone facies.

WESTWATER CANYON SANDSTONE MEMBER

The Westwater Canyon Member (Gregory, 1938, p. 59) ranges from 40 to more than 200 feet in thickness in the Ute Mountains area and averages about 100 feet. Slightly more than 240 feet of the member was measured at the south end of the Ute Mountains. The sandstone beds in the Westwater Canyon are pale yellow gray to light brown on fresh surfaces and weather to light yellow gray or yellow. They are composed of fine- to medium-grained subangular to subrounded quartz and numerous white, red, or pink accessory minerals. Detrital feldspar is sparse. The sandstone lenses are cross-stratified channel-fills. They form rounded and irregular cliffs.

The Westwater Canyon Member intertongues and intergrades with the mudstone beds of the Brushy Basin. It is conformable with the Recapture and may possibly intertongue with the Salt Wash. It is present throughout McElmo Canyon and to the north in Trail Canyon. The Westwater Canyon Sandstone Member is exposed in the dome south of Sentinel Peak and in Towaoc dome.

BRUSHY BASIN SHALE MEMBER

The uppermost member of the Morrison Formation, the Brushy Basin Member, was first described by Gregory (1938, p. 59) from the region around Brushy Basin, Utah. It is composed of bentonitic varicolored mudstone that forms slopes and becomes hard and frothy appearing where weathered. The frothy appearance is a result of swelling and subsequent drying of bentonite in the mudstone. Swelling muds are not known in the lower members of the Morrison nor in the overlying Burro Canyon Formation. Moderately persistent interbeds of thin resistant, very fine grained silicified sandstone and siltstone are common in the Brushy Basin Member. Conglomerate and conglomeratic sandstone are uncommon, although in many places green friable conglomeratic sandstone about 20 feet thick occurs near the middle of the member. Locally, where the Brushy Basin is thin and the Burro Canyon is thick, the conglomerate is near the top of the member. The conglomerate contains many fragments of igneous rock.

The lower part of the Brushy Basin intertongues with the Westwater Canyon Sandstone Member in places, but in others the contact appears to be a nearly flat surface for long distances. The base is placed at the top of the highest sandstone of Westwater Canyon lithology.

The upper part of the Brushy Basin intertongues in many places with the Burro Canyon Formation (Ekren and Houser, 1959a). Localities where intertonguing is most pronounced are generalized on the geologic map (pl. 1).

In many areas the top of the Brushy Basin is identified by a change from bentonitic to nonbentonitic mudstone. Locally, the two mudstones are separated by a ledge of silicified siltstone about 1 foot thick, particularly in exposures southwest of the Ute Mountains. In other areas, bentonitic mudstone typical of the Brushy Basin is overlain directly by conglomeratic sandstone or conglomerate typical of the Burro Canyon. In still other areas, intertonguing is extensive. Most commonly, sandstone and conglomerate typical of the Burro Canyon are interbedded with mudstone typical of the Brushy Basin, but interbedding of bentonitic and nonbentonitic mudstone has been observed in western McElmo Canyon.

The Brushy Basin forms slopes throughout McElmo Canyon and its tributary canyons in the Moqui SW quadrangle west of the Ute Mountains. It ranges in thickness from 150 to 300 feet.

The following stratigraphic sections are representative of the Morrison Formation in the Ute Mountains area. The section in lower McElmo Canyon was measured by L. C. Craig near Tozer Gulch (pl. 1) where the Recapture Member is present in sec. 32, T. 36 N., R. 18 W. The Trail Canyon section was measured by Houser and Ekren where the Recapture Member is absent in secs. 34 and 27, T. 36 N., R. 17 W.

4. *Lower McElmo Canyon section C of Craig (pl. 1)*

	Feet
Morrison Formation.	
Brushy Basin Member:	
Top contact not well exposed.	
Interval covered by debris from above except for 2 ft of grayish-red claystone at base; float indicates of white to cream claystone above. W. D. Keller reports partially devitrified ash shards from a sample a few feet from top of unit	30.9
Claystone, grayish yellow-green (5*GY* 7/2) to dusky yellow-green, slightly silty to very fine grained, sandy, hard and dense; forms two beds separated by bright-green clay parting	2.0
Claystone, very pale orange, white, and very pale green, silty to fine-grained sandy, bentonitic	32.4
Claystone, same as in unit below; contains several beds of dusky yellow-green siliceous claystone, as much as 1 ft thick, consisting of dense noncalcareous matrix and disseminated fine-grained sand	15.2

4. *Lower McElmo Canyon section C of Craig (pl. 1)*—Con.

	Feet
Morrison Formation—Continued	
Brushy Basin Member—Continued	
Claystone, very pale orange to cream, silty to slightly sandy, bentonitic; bright orange-red spots suggest incipient chert development; sample of siltstone from this unit reported by W. D. Keller to be very fine grained silica, a cherty rock which may be a secondary product from hydrolysis of volcanic ash	52.0
Sandstone, very pale orange (10*YR* 8/2) to pale-green (5*G* 7/2); weathers very pale green to light brown; fine to medium fine grained; contains subangular to rounded clear quartz and numerous pink, orange, black, green, and red accessory minerals; forms several slabby ledges	6.0
Claystone, very pale orange to grayish-orange-pink, silty to medium fine-grained, sandy, bentonitic; considerable slumping	27.0
Claystone, very pale orange (10*YR* 8/2) to grayish orange-pink (5*YR* 7/2), silty to medium fine-grained, sandy, bentonitic. In top 2 to 3 ft of unit are slabby ledges of fine- to medium fine-grained sandstone; contains numerous pink and red accessory minerals and a few chlorite flakes	32.4
Total Brushy Basin Member	197.9
Westwater Canyon Member:	
Sandstone, white to very light gray; weathers light brown; fine to medium fine grained; contains subangular clear quartz and minor pink and black accessory minerals; channeled, cross laminated; ledge lenses out laterally from section	8.5
Claystone, pale-green and greenish-gray, very sandy; float indicates; bed of bright-green hard slabby calcareous siltstone near top. Interval poorly exposed	17.9
Sandstone, pinkish-gray (5*YR* 8/1) to yellowish-gray (5*Y* 8/1); weathers yellow brown to light brown; fine to medium fine grained; contains subangular to subrounded clear quartz and numerous pink, red, and white accessory minerals; channeled, cross laminated	12.6
Claystone and sandstone; claystone, light greenish gray (5*G* 8/1) and light greenish gray (5*GY* 8/1) with vague mottling of pale red; silty to sandy, grading to nonresistant very fine to medium fine-grained clayey sandstone; this unit is the lowest predominantly green unit	30.9
Sandstone, white to light greenish-gray; weathers pale to light brown; fine to very fine grained; contains clear subangular quartz, abundant black, pink, and red and green accessory minerals, granules of light chert, and a few feldspar grains; channeled, cross laminated; ledge thickens 300 ft to east to form cliff	9.1
Total Westwater Canyon Member	79.0

4. *Lower McElmo Canyon section C of Craig* (*pl. 1*)—Con.

Morrison Formation—Continued

	Feet
Recapture Member:	
Claystone, pale-red (5*R* 6/2) mottled to pale-green, silty to medium fine-grained, sandy. Interval very poorly exposed	23.1
Sandstone, pale-yellow; weathers light brown; medium fine to fine grained; composed of subrounded to well-rounded clear quartz and numerous red and pink accessory minerals; forms rounded structureless ledge	2.8
Claystone, variably sandy, pale- to grayish-red, mottled pale-green, bentonitic. Sand is subrounded and reaches medium-fine size	4.4
Sandstone, very light gray to white and pale-yellow, very fine to medium fine-grained, poorly sorted; contains clear subangular to subrounded quartz and abundant black and minor pink, orange, and white accessory minerals; in irregular structureless beds with worm burrows	6.6
Claystone, pale-red (10*R* 6/2) to grayish-red (10*R* 4/2), silty to somewhat sandy, slightly bentonitic	8.4
Sandstone, white to pale-yellow, very fine to fine-grained; contains clear quartz and minor pink, black, and orange accessory minerals; channeled, faintly cross laminated	5.9
Claystone (70 percent) and sandstone. Claystone is silty to sandy, grayish red (10*R* 4/2) to pale green; sandstone weathers pale red to greenish brown. Unit very fine to fine grained; forms even, continuous beds; lower two-thirds poorly exposed	31.6
Sandstone, pinkish-gray, light-brown weathering, fine- to medium fine-grained; commonly contains pink, black, and white accessory minerals; weathers to rounded ledge of irregular beds	2.8
Sandstone, clayey, pale-red to dark-red to green, nonresistant; interval very poorly exposed	3.4
Sandstone, pinkish-gray (5*YR* 8/1), fine-grained; composed of clear subangular quartz and, commonly, pink, black, and white accessory minerals; channeled, cross laminated and ripple laminated; some worm burrows. Unit thickens laterally from section and fills scours that cut through underlying unit	21.4
Claystone and sandstone. Claystone grayish red (10*R* 4/2), slightly silty, flaky earthy weathering. Sandstone very light gray to pale yellow, very fine to fine grained; contains subangular clear quartz and many colored accessory minerals; horizontally laminated, platy bedded; forms 2 ft bed in middle of unit	6.7
Total Recapture Member	117.1
Salt Wash Member:	
Sandstone, white to pale-yellow, with limonite speckling; weathers pale brown; fine to medium fine grained; contains subangular to subrounded clear quartz and commonly black, white, red, and pink accessory minerals; channeled, cross laminated; contains sandy to silty red claystone parting as much as 6 ft thick off line of section	37.6
Interval covered except for upper 7 ft which is interbedded claystone and sandstone; claystone dark red and green, sandy to silty; sandstone yellowish gray, brown-weathering very fine to fine grained; contains clear quartz and pink, black, and green accessory minerals; irregular but continuous beds; float of claystone covers lower part of unit	29.2
Claystone and minor sandstone. Claystone sandy, dark red below to dark purple above. Sandstone yellowish gray (5*Y* 7/2), very fine grained; contains clear subangular quartz and numerous colored accessory minerals; sandstone forms massive, structureless ledge 1.3 ft or more thick at top of unit	13.1
Sandstone, white to pale-yellow, light-brown weathering, very fine to fine grained; contains clear subangular quartz and abundant black, dark-gray, and orange to pink accessory minerals; channeled, cross-laminated; bed appears to lens out laterally from section	17.2
Claystone and sandstone, interbedded. Claystone sandy to silty, dark red to purplish red, calcareous; sandstone greenish gray to light purplish gray, very fine to medium fine grained, finely banded. Unit forms shaly nonresistant reentrant; bottom contact is gradational, top contact sharp. Formation assignment debatable	3.8
Total Salt Wash Member	100.9
Total Morrison Formation	494.9

5. *Trail Canyon section* (*pl. 1*)

Morrison Formation:

	Feet
Brushy Basin Member (incomplete):	
Mudstone, green. Total incomplete Brushy Basin Member	22
Westwater Canyon(?) Member:	
Sandstone, pale yellow-gray to light-yellow, fine-grained; composed of subrounded quartz, opaque white clay(?) grains (5 percent); soft, friable; upper 2 ft is quartzite; forms ledge; joints strike N. 40° W., dip 80° SW	34
Mudstone, green, mostly covered	19
Total Westwater Canyon(?) Member	53
Salt Wash Member:	
Sandstone, light-gray, fine-grained, friable, quartzose; calcareous cement; abundant fine limonite spots	7

5. *Trail Canyon section (pl. 1)*—Continued

	Feet
Morrison Formation—Continued	
Salt Wash Member—Continued	
Sandstone, light-gray, yellow-gray weathering; fine-grained; calcareous cement; quartzite in basal 1.5–2.0 ft grades upward to soft, friable sandstone; contains abundant limonite and traces of very fine opaque white grains; 0.2-ft green flat-bedded mudstone at top	11
Sandstone; grayish tan, fine grained, and thinly flat bedded at base; grades to light yellow gray, fine to medium fine grained at top; firmly cemented at base to weakly cemented at top; limonitic, very sparse biotite(?) fragments at base; very sparse pale-orange grains present throughout; thin green mudstone at top	12
Covered; believed predominantly siltstone, clayey; contains a few thin layers of hard silicified sandstone	6
Sandstone, light-gray, limonite-spotted, pale-brown-weathering; contains fine-grained quartz, opaque white clay grains, sparse, very fine rounded pale-orange grains, interstitial black MnO_2(?) flakes, very sparse black opaque grains, angular opaque white to pale-green clay grains, and green and pale-green grains; thick bedded	12
Sandstone, light-gray to white, limonite-stained, fine- to medium fine-grained; contains subrounded clear quartz; commonly contains white opaque fine angular clay grains, sparse to common very fine rounded pale-orange grains, green mud pellets and clay galls, very sparse fine angular green grains, sparse pink quartz grains, interstitial light-gray to white clay, numerous green mudstone partings, limonite flakes, and calcareous cement; joints are N. 55° W. 70° SW	48
Sandstone, light-gray to white, pink-weathering, very fine to fine-grained; contains sparse, very fine orange grains; weathers to rounded nobular hoodoos; thin (1–2 ft) green mudstone at top	15
Siltstone and sandstone, very fine grained, partly covered	16
Sandstone, light-gray, fine- to medium fine-grained; contains subrounded quartz grains and sparse subrounded orange and pink grains; calcareous cement; friable; has interstitial mudstone; calcite-filled joint trends N. 50° W	16
Sandstone, light-gray, fine-grained; contains subrounded to subangular quartz grains and sparse very fine orange grains (feldspars?), calcareous cement; current lineations N. 15° E.; crossbedded, lenticular; fills channel in mudstone of unit 1	16
Mudstone, red, purple, reddish-gray, sandy	42
Total Salt Wash Member	201

Base of Morrison Formation.
Top of Junction Creek Sandstone.

CRETACEOUS SYSTEM

BURRO CANYON FORMATION

In the Ute Mountains area, the Burro Canyon Formation (Stokes and Phoenix, 1948) ranges from 30 to 200 feet in thickness and consists of green, predominantly nonbentonitic mudstone interbedded with lenses of conglomerate and conglomeratic sandstone that vary considerably in number and thickness. Red mudstone occurs sporadically in the lower part of the formation. The nonbentonitic mudstone weathers hackly or fissile.

The conglomerate and conglomeratic sandstone are commonly white or light gray. They contain pebbles and granules of colored chert, silicified limestone, and siltstone in a matrix of quartz sand. Fragments of petrified wood and silicified dinosaur bone are common in the lowermost lenses. Carbonized plant remains are extremely rare. The conglomerate lenses in the upper part of the formation are more numerous, finer grained, and blanket larger areas than those in the lower part.

The lowest unit in the Burro Canyon Formation, a system of shoestring lenses of conglomerate and conglomeratic sandstone, has been named the Karla Kay Conglomerate Member from an exposure at the Karla Kay mine in McElmo Canyon (Ekren and Houser, 1959a). The Karla Kay is highly resistant to weathering, and forms vertical cliffs and dark-brown knobby outcrops. The shoestring lenses or channel fillings are rarely more than 2,000 feet wide or more than 65 feet thick; commonly they are 500 to 800 feet wide. The channel fillings have been undercut in many areas, and their former locations are marked by huge, resistant, dark blocks—many as large as a house—that have slumped down the slopes of soft underlying mudstone. Where the Karla Kay Conglomerate Member is absent, the base of the Burro Canyon is marked either by hackly-weathering mudstone or by fine-pebble and granule conglomerate or sandstone. These rocks, although basal, are stratigraphically younger than the Karla Kay.

Stratigraphic sections of the Burro Canyon follow. Section 6 was measured by Ekren in sec. 2, T. 35 N., R. 19 W., and sec. 35, T. 36 N., R. 19 W., about half a mile north of Colorado Highway 32. Section 7 was measured by Houser and Ekren in sec. 30, T. 36 N., R. 18 W., on the northwest side of Tozer Gulch, about three-quarters of a mile west-northwest of the Karla Kay mine.

6. *Wood Chuck section (pl. 1)*

Dakota Sandstone.
Disconformity.
Burro Canyon Formation:

Sandstone, conglomeratic, white, weathering white; contains granules and pebbles of white chert, sparse red chert; grades to very fine to

6. *Wood Chuck section (pl. 1)*—Continued

	Feet
Burro Canyon Formation—Continued	
medium grained sandstone at top; massive weathering; forms a cliff	70.0
Mudstone, green-gray; weathers hackly and fissile without significant swelling	50.0
Sandstone, conglomeratic, pale-brown to white; weathers buff and brown; cross-stratified (festoon type); pebbles and granules mostly colored chert as much as ¾ in. in diameter; white chert common	20.0
Total Burro Canyon Formation	140.0

7. *Tozer section (pl. 1., section 7)*

Dakota Sandstone (not measured).	
Erosional disconformity, relief of about 2 feet.	
Burro Canyon Formation:	
Sandstone, white, fine-grained; carbonate cement; contains subangular quartz	2.0
Mudstone, green; weathers hackly, without significant swelling	15.5
Sandstone and conglomerate; sandstone light tan gray, medium- to coarse-grained, interbedded with conglomerate (granules to pebbles as much as 1½ in. in diameter); pebbles consist mostly of chert and some quartzite and silicified limestone; unit forms rounded, blocky, vertical cliff	32.0
Mudstone, pale-green; weathers hackly, without significant swelling	46.0
Mudstone, pale-green and red, well-silicified; forms resistant ledge	2.0
Mudstone and sandstone, interbedded; sandstone, very light gray, fine-grained; forms thin ledges, predominates in lower one-third and decreases upward, poorly exposed; mudstone, very light gray, silty; weathers hackly, without significant swelling	44.5
Karla Kay Conglomerate Member:	
Conglomerate, very pale tan-gray to pale grayish-green; weathers dark brown and black; firmly cemented; subrounded pebbles range from ½ to 2½ in. in diameter, averaging about 1 in., pebbles consist mostly of brown, gray, blue-gray, green-gray, and red-brown chert; matrix of coarse-grained clayey sandstone; conglomerate and sandstone silicified somewhat differentially but generally along bedding; unit cross-stratified (festoon type), with troughs plunging eastward; forms massive cliff with very knobby surface due to pebbles; dinosaur bones and silicified trees common. Unit occurs as nonpersistent lenses about 600 ft wide. Total Karla Kay Conglomerate Member	64.0
Total Burro Canyon Formation	206.0

The amount of conglomerate and sandstone in the Burro Canyon Formation decreases southward within the map area, and in many exposures in the south the Burro Canyon is entirely mudstone. Just south of Sentinel Peak (the "East Toe" of the Ute Mountains), about 3 miles southwest of Towaoc, Colo., the Burro Canyon consists of approximately 30 feet of hackly weathering mudstone. Farther south, in the Carrizo Mountains of New Mexico and Arizona, the upper part of the Morrison Formation as mapped by Strobell (1956) contains lenses of conglomeratic sandstone that may be equivalent to those of the Burro Canyon of southwestern Colorado, although no mudstone typical of the Burro Canyon is present.

The top of the Burro Canyon Formation is an erosional disconformity observed throughout the Ute Mountains area. The relief on this surface ranges from a few inches to more than 40 feet within a distance of 300 feet. White quartzite, sandstone, or less commonly, mudstone of the Burro Canyon Formation are found at this erosion surface in different parts of the area.

The erosional disconformity has been observed in other areas of the Colorado Plateau (Carter, 1957), but in places in the Slick Rock district in southwestern Colorado approximately 30 miles northeast of the Ute Mountains the Dakota Sandstone rests conformably upon the Burro Canyon (Simmons, 1957).

The change in the Burro Canyon southward within the Ute Mountains area suggests that this area may have been near the southern or southeastern edge of the area of deposition of coarse clastic material during Burro Canyon time. In the Four Corners area of New Mexico and Arizona, thin discontinuous lenses of conglomeratic sandstone typical of the Burro Canyon Formation are interbedded with mudstone typical of the Brushy Basin, and within a few feet of the Dakota Sandstone (stratigraphic section 8). The thinness or absence of the Burro Canyon in this region is probably due primarily to pre-Dakota erosion but may be due, in part, to a facies change southward from the Ute Mountains area. Farther south the Dakota lies on successively older formations (Craig and others, 1955, p. 161).

Brown (1950), Katich (1951), Stokes (1952), and Simmons (1957) have presented evidence that the Burro Canyon, or its equivalent in central Utah, the Cedar Mountain Formation (Stokes, 1944, 1952), is of Early Cretaceous (Aptian) age. Simmons (1957) reports that invertebrate fossils in upper beds of the Burro Canyon in the Slick Rock mining district were identified as Early Cretaceous. The fossils correlate with an Early Cretaceous fauna in Wyoming or Montana which in turn contains fossils found in the Cedar Mountain Formation of Utah.

Little, if any, break in deposition occurred between the Morrison and Burro Canyon Formations in the Ute Mountains area. The complete lack of fossils in the vicinity of the contact prevents precise determination of the boundary between the Jurassic and Cretaceous Systems.

DAKOTA SANDSTONE

The Dakota Sandstone of Late Cretaceous age ranges in thickness from 95 to 140 feet but averages 125 feet in most of the Ute Mountains area. It is composed of yellow-gray and tan carbonaceous sandstone of fluvial origin in the lower part and yellow-brown and yellow-gray sandstone of fluvial and beach origin in the upper part. These are interbedded with gray to dark-gray carbonaceous mudstone and coal that were probably deposited in a swamp or tidal-flat environment. The coal beds are not persistent and range from a few inches to 3 feet in thickness. Sandstone cemented with iron oxide is common in the upper part of the formation.

Two complete stratigraphic sections of the Dakota, measured southwest of the mountains, follow. Section 8 was measured in sec. 6, T. 34 N., R. 18 W.; section 9 in sec. 10, T. 33½ N., R. 19 W. Both sections were measured by J. H. Irwin, Houser, and Ekren.

8. *Yucca section (pl. 1)*

	Feet
Block rubble.	
Unconformity.	
Dakota Sandstone:	
Mudstone and coal, gray to black, very thin bedded. Unit forms a smooth, covered slope; it is carbonaceous mudstone at base and grades to coal at top; base sharp	3.5
Sandstone, light-gray, yellowish-gray-weathering, very fine grained; contains subangular quartz, rare black accessory minerals, firm calcareous cement; grades to siltstone; flat, thin bedded; weathers slabby, forms a ledge; contains carbonized plant fragments, and ironstone concretion zones which are parallel to the bedding planes; base sharp	1.0
Sandstone, pale yellow-gray to yellowish-brown, fine- to very fine-grained, well-sorted; contains subrounded to subangular frosted quartz, abundant argillaceous material (accessories obscured by iron stains), firm calcareous and ferruginous cement; wedge-plane crossbedding; weathers blocky, forms a ledge; bedding contorted; contains sparse plant fragments and a few ironstone concretions which weather out as spheroidal nodules; base sharp	5.0
Sandstone, pale brownish-gray; weathers yellowish brown and yellowish gray; medium to fine grained; contains quartz and, at intervals, abundant argillaceous material (accessories obscured by iron stain); firmly cemented, calcareous and limonitic; flat, thin-bedded; weathers flaggy, forms a ledge; contains abundant films of carbonaceous material and epigenetic seams of calcite along horizontal fractures; base sharp	2.5
Mudstone, very dark gray to black, fissile to thin-bedded; forms a regular slope; unit is very carbonaceous; contains ironstone concretions at the top in a zone as much as 8 in. thick; base sharp	10.0

8. *Yucca section (pl. 1)*—Continued

	Feet
Dakota Sandstone—Continued	
Sandstone, dark-gray, yellowish-gray weathering; very fine grained; grades to siltstone; well-sorted; composed of subangular quartz and argillaceous material; firm calcareous cement; very thin bedded; weathers rounded, forms a ledge; contains sparse limonite and abundant plant fragments; base sharp	3.5
Mudstone, light- to medium-gray, thinly to very thinly laminated; forms a regular slope; unit is carbonaceous; upper 3 ft very impure coal containing limonite particles	17.0
Ironstone and autochthonous chert zone, dark-red, sandy; base gradational	1.0
Sandstone, yellowish-gray, yellowish-brown; weathering very fine grained, fairly well sorted; grades to siltstone; composed of frosted quartz; poorly cemented, limonitic; thinly cross laminated (rib and furrow); forms a ledge; contains abundant calcareous films and limonite stains, spots, and streaks; base gradational	3.5
Mudstone, silty, dark-gray; indistinct bedding; weathers hackly; forms a slope; base gradational	3.0
Coal, impure	2.5
Mudstone, silty, dark-gray; indistinct bedding	3.0
Sandstone, light-gray; weathers pale yellowish gray; medium- to fine-grained, fairly well sorted; contains subrounded frosted quartz, some minor argillaceous material, firm calcareous cement; thin bedded planar crossbedding; weathers smooth to slabby, forms a ledge; contains some powdery calcite and limonite flecks on fresh fracture	3.0
Sandstone, light-gray, medium- to fine-grained; contains subrounded quartz, firm calcareous cement; thin bedded; weathers knobby, forms a slope; contains common iron stains and abundant carbonaceous material; 1-ft-thick dark-gray carbonaceous mudstone at top; base sharp	6.0
Carbonaceous mudstone, dark-gray, thinly laminated; weathers fissile, forms irregular slope; base gradational	1.5
Siltstone (contains some claystone), gray, poorly sorted, thin-bedded; weathers blocky, forms a slope; contains abundant carbonaceous material and sparse limonite; base gradational	1.0
Mudstone (silty with minor sand grains), dark- to medium-gray; fissile bedding; forms an irregular slope; unit very carbonaceous at base, becomes sparsely carbonaceous toward top; base gradational	15.0
Sandstone, medium-gray; weathers pale yellowish gray; medium- to very fine-grained; contains some siltstone, poorly sorted and subrounded frosted quartz, rare black and orange accessory minerals; argillaceous material common; flat, thin bedded; weathers smooth, forms a ledge. This unit is discontinuous; base sharp	1.0
Mudstone, very sandy; grades to muddy sandstone; light gray, weathers mottled gray and yellow; medium to very fine grained to silt size, poorly sorted, weakly cemented, probably calcareous; flat, thin to very thin bedded; forms a slope; contains limonite stains and some clay-size matrix material	

8. *Yucca section (pl. 1)*—Continued

	Feet
Dakota Sandstone—Continued	
which resembles Brushy Basin Member of Morrison. This unit grades to sandstone horizontally in both directions of exposure; base flat	13.0
Sandstone, white to very light gray, pale-yellow-weathering; very fine grained to silt size, fairly well sorted; contains frosted quartz, rare to common black, orange, and green accessory minerals and argillaceous material; flat, thin bedded; weathers smooth, forms a ledge; contains medium-grained quartz "berries" and a few limonite specks; base sharp	5.0
Total Dakota Sandstone	101.0
Top of Burro Canyon Formation.	

9. *Kiva section (pl. 1)*

	Feet
Mancos Shale (not measured):	
Sandstone, yellow, soft, friable.	
Dakota Sandstone:	
Sandstone, pale yellowish-gray, tan-weathering; fine to very fine grained, sugary, well sorted; contains subrounded frosted quartz, black accessory mineral grains, weak limonite cement; unit is a coset composed mainly of flat beds, some wedge-planar-type crossbeds, and some concave low-angle crossbeds; weathers knobby to slabby, forms a ledge; contains limonite stains; base sharp	4.5
Mudstone and impure coal, medium-gray to black, flatbedded; weathers hackly, forms an irregular slope; contains limonite pockets; base sharp	4.0
Sandstone, pale yellowish-gray, tan-weathering; fine grained, sugary, well sorted; composed of subrounded quartz; weakly cemented (iron); unit is a coset composed of flat thin to thick beds, wedge-planar-type crossbeds, and some concave low-angle crossbeds; weathers pitty and slabby, forms a ledge; contains rib and furrow and secondary silica overgrowths; base sharp	8.0
Mudstone, dark-gray, flat-bedded; weathers fissile; mostly a covered interval; contains abundant carbonaceous material and some limonite; base sharp	5.5
Sandstone, gray, weathers light-gray; abundant yellow limonite staining; carbonaceous, fine to very fine grained, well sorted; contains subrounded to subangular quartz; thick bedded; weathers massive and blocky, forms an irregular ledge; contains pitted surface marks, abundant carbonized plant remains, and, at top of the unit, a 3-ft bed of impure coaly material and hackly-weathering carbonaceous mudstone; contains pale greenish-yellow material; base sharp	13.0
Mudstone, medium-gray to black to yellowish-gray, carbonaceous; weathers hackly, forms a slope; contains limonite stains and beds of impure coal; base sharp	11.0
Ironstone, dark-red, flat-bedded, cherty; weathers blocky to knobby, forms an irregular ledge; contains abundant hematite and limonite; base sharp	1.0
Mudstone, same as mudstone unit above	15.5

9. *Kiva section (pl. 1)*—Continued

	Feet
Dakota Sandstone—Continued	
Sandstone, light yellowish-gray, buff-weathering; medium grained, well sorted; contains rounded, frosted quartz, black accessory minerals; weakly cemented by limonite(?); unit is a coset containing flat thin beds, and wedge-planar crossbeds, and small-scale crossbeds; weathers smooth to blocky, forms a ledge; contains masses of rounded medium-grained sandstone, firmly cemented with calcite; base gradational	28.0
Conglomerate, pale yellowish-gray. Matrix is fine-grained sandstone composed of subrounded to subangular frosted quartz, firmly cemented. Pebbles are quartzite, red chert. Unit is a coset containing flat thin beds, wedge-planar-type crossbeds and low-angle small-scale concave crossbeds; weathers smooth, forms a ledge; unit is short channel or lens, thickness reaches 6 in. a short distance on either side of the point measured; coarser material concentrated along the bounding surfaces of cross-bedded sets; base irregular and gradational	4.0
Sandstone, pale-yellow, medium-grained, well-sorted; contains subrounded frosted quartz, quartz overgrowths; weakly cemented (calcareous and limonitic); wedge- and tabular-planar crossbeds and concave low-angle small-scale crossbeds; weathers blocky to knobby, forms an irregular ledge; thickness varies considerably laterally; base gradational	7.0
Sandstone, gray to brownish-gray; weathers to dark brownish-gray; medium grained, fairly well to poorly sorted; contains rounded quartz, red, orange, and sparse green chert, firm cement (calcareous), flat bedding; weathers blocky, forms an irregular ledge; contains calcite overgrowth; unit grades upward into overlying unit; base sharp	3.0
Mudstone (mostly covered), carbonaceous, dark-gray, flat, thinly laminated; weathers fissile, forms a slope; base concealed	4.0
Sandstone and rare short conglomeratic beds, white, light-gray-weathering, medium-grained, well-sorted; contains subangular sugary quartz, rare black accessory minerals, weak cement; wedge- and tabular-planar crossbeds and low-angle small-scale crossbeds; weathers rounded to pitty to knobby, forms an irregular ledge; contains abundant limonite at base; flashes in sunlight owing to quartz overgrowths; base gradational	10.0
Sandstone, light-gray, pale yellowish-gray-weathering; medium to fine grained, well sorted; contains rounded frosted quartz, rare black accessory minerals, firm cement (calcareous?); flat, thin beds (rib and furrow); weathers blocky, forms a ledge; contains abundant limonite spots and stains; base sharp	3.0
Mudstone, carbonaceous, dark-gray, flat-bedded; weathers fissile, forms a slope; contains a 6-in. flaggy gray beige-weathering sandstone about 1 ft from base; composed of angular quartz, abundant limonite cement; contains a few iron concretions; base sharp	4.5

9. *Kiva section (pl. 1)*—Continued

	Feet
Dakota Sandstone—Continued	
Sandstone, very pale yellow, light grayish-yellow, weathering, fine-grained, sugary, well-sorted; contains subangular, frosted quartz, weak cement (calcareous); unit is a coset composed of flat thick-bedded sets, wedge-planar crossbedded sets, and low-angle crossbeds; weathers smooth to blocky, forms a ledge; desert varnish on resistant bedding surfaces; contains limonite spots and streaks; quartz flashes in sunlight owing to secondary quartz overgrowths	6.0
Sandstone and short conglomeratic units, light-gray, coarse- to medium-grained, poorly sorted; contains rounded to subrounded frosted quartz, pebbles of quartzite, red chert, and clay; firmly cemented (calcareous?); wedge-planar type crossbedding (concave, low- to medium-angle, medium-scale crossbeds); weathers blocky, forms a ledge; contains limonite stains and some argillaceous material; base gradational	7.0
Conglomerate, mottled gray and red; weathers light gray. Matrix is coarse-grained quartz sandstone. Pebbles in unit comprise quartzite, clay fragments, chert, and siliceous limestone(?). Unit weathers blocky, forms a ledge; contains a 2-in. sandstone layer at the base which is gray, medium grained, and well sorted and contains abundant carbon and limonite; base sharp	1.0
Total Dakota Sandstone	140.0
Top of Burro Canyon Formation.	

The fluviatile sandstone beds in the lower part of the Dakota are much like the sandstone in the upper part of the Burro Canyon Formation; where the disconformity between the two formations is not apparent, distinction is difficult. Several criteria were used to distinguish the two formations, and these gave reliable results in mapping:

Burro Canyon Formation	*Dakota Sandstone*
Carbonaceous material absent or scarce.	Carbonaceous material common in all types of strata.
Sandstone beds are commonly conglomeratic and white.	Sandstone contains very little conglomeratic material except in lowermost beds and are yellow-brown or yellow-gray.
Mudstone beds are mostly green and red; a few are very light gray to white.	Interbedded mudstone commonly is medium gray to black, and, very rarely, light gray.
Mudstone pebbles in conglomeratic material are red or green.	Mudstone pebbles in basal beds are mostly gray or black, but some are green, white, and red.

In figure 5 the contrasting colors of the Dakota Sandstone and the sandstone beds of the Burro Canyon Formation are apparent.

The basal conglomerate of the Dakota has a maximum thickness of about 5 feet and is absent locally.

FIGURE 5.—Lower part of Dakota Sandstone (Kd) and sandstone of Burro Canyon Formation (Kb) display contrasting colors in western McElmo Canyon. Rounded slopes in middle ground are on Brushy Basin Member (Jmb) of Morrison Formation. Sandstone outcrops in foreground are in Westwater Canyon Member (Jmw) of Morrison Formation. Viewed from the west.

Most of it is granule conglomerate but some is pebble conglomerate. In areas of relatively high pre-Dakota relief, slabs, chips, and, rarely, cobbles and boulders of quartzite are present in the conglomerate. Most of the granules and pebbles are chert and quartzite, although pebbles of mudstone and sandstone are common locally.

The sandstone beds in the lower part of the Dakota are cross-stratified at high angles. These beds are highly lenticular and have little value for structural interpretation. The uppermost sandstone bed in the Dakota is fairly continuous throughout the Ute Mountains area and is a useful horizon marker. The top of the Dakota was mapped at the top of this sandstone bed. The bed contains fossil pelecypods and is probably a reworked beach deposit. The pelecypods are the same as those occurring a few feet higher in the Mancos Shale, identified by W. A. Cobban (written commun., 1956) as *Gryphaea* n. sp.

The assignment of an age to the Dakota Sandstone is based on its lithologic similarity to the Dakota elsewhere on the Colorado Plateau where it overlies the Burro Canyon Formation and where a Late Cretaceous age has been established (Brown, 1950). Katich (1951, p. 2094) mentioned, however, that faunal evidence indicates that in parts of central Utah the lithologic unit called Dakota Sandstone is Early Cretaceous in age. Early Cretaceous fossils also have been found in a lower sandstone of the Dakota in the Carrizo Mountain area (J. D. Strobell, oral commun., 1957). In the latter areas the Burro Canyon Formation has not been recognized. Where the Burro Canyon Formation is recognized, the Dakota Sandstone is therefore apparently of Late Cretaceous age, and it is assigned this age in the Ute Mountains area.

MANCOS SHALE

Cross and Purington (1899) named and described the Mancos Shale exposed along the Mancos River in eastern Montezuma County, Colo., where they estimated a thickness of 1,200 feet. The Mancos Shale in the Ute Mountains region consists of 1,900 feet of beds composed almost entirely of gray to dark-gray gypsiferous shale. The following section was measured by Houser, J. H. Irwin, and Ekren south of the Ute Mountains in secs. 24 and 25, T. 33½ N., R. 19 W., on the north slope of "The Mound" (pl. 1).

10. *Mound section (pl. 1)*

	Feet
Top of local exposure.	
Pediment deposits.	
Unconformity.	
Mancos Shale (incomplete):	
Mudstone, pale yellow-gray, fissile-bedded; weathers hackly, forms a regular slope; base gradational	18
Sandstone, very light gray; weathers buff; very coarse to coarse grained, poorly sorted; contains subrounded clear and frosted quartz, abundant glauconite, and rounded grains of quartzite(?) and chert(?); medium to thin beds, small-scale low-angle crossbedding; weathers slabby; forms an irregular ledge; interbedded with fissile dark-gray mudstone; contains shark teeth; base sharp	9
Juana Lopez Member:	
Limestone and mudstone, interbedded, dark gray; fissile bedding. Limestone thin-bedded (0–2 in. thick, average ½ in.), pale yellow gray, finely crystalline, very fossiliferous; contains pelecypods (*Inoceramus perplexus* Whitfield and *Ostrea lugubris* Conrad) and skate tooth (*Ptychodus whipplei* Marcou). Six ft above base of unit is fine-grained limy sandstone lens (6 in. thick) that contains frosted quartz, abundant black accessory minerals, and argillaceous material; weathers rounded to blocky, forms a ledge; base of sandstone lens sharp. Limestone-mudstone unit forms an irregular cliff; base gradational.	
Total Juana Lopez Member	42
Mudstone, dark-gray to black; weathers dark gray; very thinly laminated; weathers hackly, forms a regular slope; contains carbonaceous material and limestone concretions similar to concretionary units below; base gradational	62
Limestone concretionary zone in shale unit; concretions are dark gray, weather tan to buff and rounded to blocky; a 3- to 6-in. zone at base contains same crystalline cone-in-cone structure noted in concretionary unit below; in some places this structure occurs at top of limestone concretions; limestone not composing this crystalline structure is partly fossiliferous (*Lingula*-like pelecypods); some of upper surfaces of the limestone are rounded and nodular; contains vugs lined with calcite crystals; basal 3- to 6-in. zone contains some banding; base sharp	2
Mudstone, dark-gray to black; weathers dark gray; lacks limestone concretions	33
Limestone concretionary zone in shale unit, dark-gray; weathers brown; concretions are 1 to 5 ft in diameter, bounded by 4- to 6-in. zone of radiating crystalline cone-in-cone structure	2
Mudstone, gray to dark-gray; fissile bedding, calcareous; forms a regular slope; interval is mostly covered; contains fossils and in places abundant gypsum; base gradational	266
Greenhorn Limestone Member:	
Limestone, dense, gray; weathers light gray to white; slightly sandy, flat, thin bedded, discontinuous lenticular; intertongues with mudstone above and below; weathers to flat cobbles, forms a thick ledge; has conchoidal fracture.	
Total Greenhorn Limestone Member	20–33

10. *Mound section (pl. 1)*—Continued

	Feet
Mancos Shale (incomplete)—Continued	
Mudstone, gray, silty; contains a few black accessory minerals; weathers hackly; forms a regular slope; zone, about 1 ft thick, 2 to 3 ft below the top of the unit, which contains abundant shells of *Gryphaea newberryi*	40
Sandstone, poorly cemented except for a 1- to 2-ft bed 14 ft below top of unit; yellow, limonite stained, medium grained; contains subrounded quartz, rare green accessory minerals; base gradational	20
Sandstone, same as unit below except gray and contains no limonite; zone 4 ft from base is firmly cemented (calcareous)	10
Sandstone, yellow-gray, fine-grained; contains subangular frosted quartz, abundant green accessory minerals; poorly cemented (calcareous and ferruginous); indistinct bedding; weathers to soil; forms irregular slope; base sharp	7
Total incomplete Mancos Shale	544
Dakota Sandstone (incomplete):	
Sandstone, pale yellow-gray, weathering yellow gray, medium- to fine-grained, well-sorted; contains subrounded frosted quartz, common black and red accessory minerals; firmly cemented (calcareous) thick beds; wedge-planar low-angle small-scale crossbedding; forms rounded ledge; contains abundant calcareous material, and limonite stains, streaks, and spots, and a 2-in. coal bed about 10 ft below top. Total incomplete Dakota Sandstone	15

The transition from swamp, tidal flat, and beach deposition during late Dakota time to marine deposition in Mancos time was gradual. In the southern and southwestern parts of the area, the Mancos sea reworked sands of Dakota age and deposited a pale-yellow to light-tan, weakly consolidated, structureless clayey sandstone about 35 feet thick. Fossils from this sandstone were identified by W. A. Cobban (written commun., 1956) as *Gryphaea* n. sp.

Two conspicuous lithologic marker units are present in the lower part of the Mancos: the Greenhorn Limestone Member of the Mancos Shale (see Dane, 1957, and Wanek, 1959, p. 681), about 75 feet above the base, and the Juana Lopez Member of the Mancos Shale, about 475 feet above the base of the Mancos.

The Greenhorn Limestone Member is remarkably persistent throughout the map area although it ranges in thickness from 15 to about 35 feet. It consists of thin beds of dense, locally almost lithographic, gray limestone interbedded with shale. The limestone weathers to light gray or white and forms low ledges. Three to six feet below the base of the limestone is a persistent bed, 3 inches to 3 feet thick, composed almost entirely of shells of *Gryphaea newberryi* Stanton (W. A. Cobban, written commun., 1956). About a foot above this bed is a 6- to 12-inch very light gray bed of bentonite stained by limonite. The Greenhorn Limestone Member is a conspicuous marker on flanks of the Ute Mountains. It is not shown separately from the Mancos on the map (pl. 1).

The Juana Lopez Member is composed of brown to tan sandy fossiliferous limestone interbedded with dark-gray shale. It was originally defined by Rankin in 1944 (p. 12, 19–20) in a section measured 6 miles northwest of Cerillos, Santa Fe County, N. Mex., as a very calcareous thin-bedded, very fossiliferous sandstone 10 feet thick that occurs near the top of the Carlile Shale in northern New Mexico and that contains *Prionocyclus wyomingensis* Meek and *Inoceramus labiatus* Schlotheim. Rankin, in fact, considered the top of the Juana Lopez Sandstone Member as the top of the Carlile Shale.

In the Ute Mountains area, the Juana Lopez consists of 42 feet (Mound section) of very fossiliferous, finely crystalline pale yellow-gray limestone and interbedded dark-gray fissile mudstone. The member contains *Inoceramus perplexus* Whitfield, *Ostrea lugubris* Conrad, *Ptychodus whipplei* Marcou, *Prionocyclus wyomingensis* Meek, and *Inoceramus dimidius* White (W. A. Cobban and J. B. Reeside, Jr., 1956, written commun.). This assemblage suggests a Carlile age for the Juana Lopez Member in the Ute Mountains.

The basal contact of the Juana Lopez Member is gradational and is placed at the base of the lowermost prominent limestone bed. The top of the member is placed at the top of uppermost limestone; however, as mapped in the mountains, and as far south as "The Mound" (pl. 1; fig. 6), the Juana Lopez Member includes at its top a set of light-gray glauconitic cross-stratified coarse-grained quartz sandstone beds a few inches to as much as 9 feet thick. South of "The Mound," however, two beds of this sandstone are separated by about 40 feet of gray shale.

In this area the combined thicknesses of the Juana Lopez Member and the overlying interval as defined by these two sandstones is nearly 100 feet thick, whereas at "The Mound" it is 50 feet thick, and northward in the mountains proper it is less than 25 feet thick. Since the completion of the present study, C. H. Dane (1960) reported that the glauconitic sand overlying the Juana Lopez Member at "The Mound" is of Niobrara age, containing *Inoceramus deformis*. According to Dane (1960, p. 53) the glauconitic sandstone cuts sharply downward across underlying beds northward from the San Juan River. Dane reported (p. 53): "At a locality 3 miles south of the Colorado State line coarse-grained glauconitic sandstone rests directly on shales of Carlile

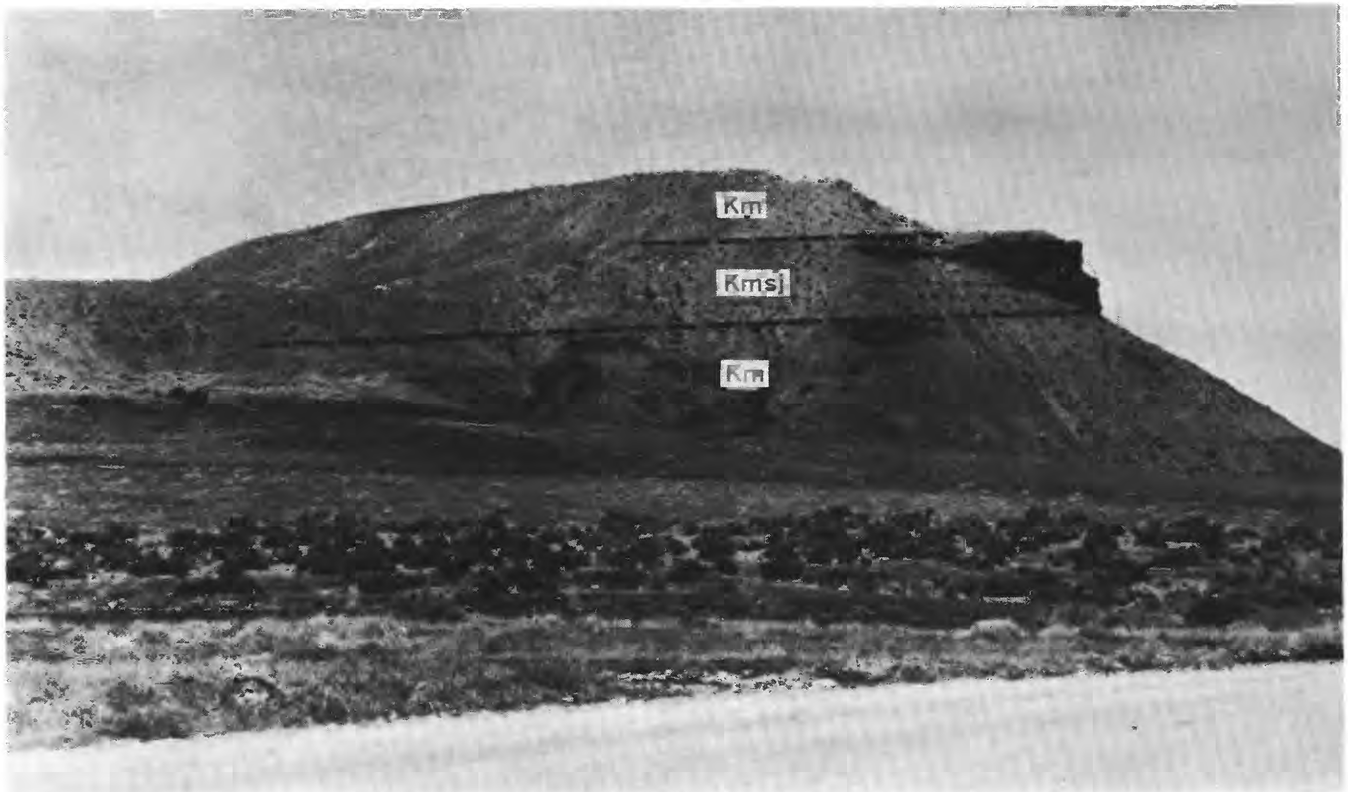


FIGURE 6.—"The Mound." The Juana Lopez Member (Kmsj) in the Mancos Shale (Km).

age within 60 feet of Rankin's Juana Lopez sandstone member. West of Towaoc, Colo. (loc. 8), south of Ute Mountains, coarse-grained glauconitic quartz sandstone containing *Inoceramus deformis* of Niobrara age rests on only 15 feet of shale above the Juana Lopez sandstone member. It is of interest to note that the basal few inches of the glauconitic sand contains a few shells of *Ostrea lugubris*, doubtless reworked from the underlying shales in which it is also present." Dane concluded (p. 53) that beds of the *Inoceramus deformis* zone cut down unconformably northward and that 300 feet or more of beds present south of San Juan River are missing just south of Ute Mountains about 30 miles to the north.

The Juana Lopez Member is sporadically exposed in cuestas along the lower flanks of the Ute Mountains from "The Mound" to Towaoc, Colo., and forms a low ridge across the southern part of the Cortez SW quadrangle. North of the Yucca cluster of laccoliths, along the Western slopes of the mountains, the member is hidden by talus and debris and its location is not certain. The member is probably continuous throughout the Ute Mountains, but it could not be traced in the higher parts owing to heavy cover of vegetation and soil, the nonresistant nature of the limestone, and general thinning of the member, especially toward the north. The Juana Lopez Member a few hundred yards east of Towaoc is so deficient in limestone that it has no topographic expression.

The lower part of the Mancos Shale in the vicinity of Point Lookout, 25 miles east of the Ute Mountains, is of Colorado age and the upper part is of early Montana age (Pike, 1947, p. 20–24). (For a discussion of the terms Colorado Group and Montana Group and of the faunal evidence for these divisions, see Pike 1947, p. 20.) The Mancos in the Ute Mountains is similar to that near Point Lookout and almost certainly correlative with it.

MESAVERDE GROUP

The Mesaverde Group of Late Cretaceous age is preserved in many places in western Colorado. It was first described by Holmes (1877, p. 245, 248). Later, the major subdivisions were named by Collier (1919, p. 296) from bottom to top: the Point Lookout Sandstone, 120 feet thick, the Menefee Formation, 800 to 900 feet thick, and the Cliff House Sandstone, 190 feet thick. In the vicinity of the San Juan River in southwestern Colorado and northwestern New Mexico the group ranges from 1,200 to 1,500 feet in thickness.

Only the Point Lookout Sandstone is present in the Ute Mountains.

POINT LOOKOUT SANDSTONE

Overlying the Mancos Shale on a few high places in the Ute Mountains are thin flat persistent beds of buff and yellowish-gray sandstone interstratified with dark-gray mudstone that resembles that of the Mancos. This sequence is believed to be the lower part of the Point Lookout Sandstone of the Mesaverde Group because of its lithologic similarity to that sandstone at the type locality. The maximum preserved thickness is about 100 feet. The beds are silicated where intruded by diorite and granodiorite northwest of the Black Mountain stock. In the vicinity of "The Knees" stock, the Point Lookout rocks are slightly recrystallized and contain abundant crystals of pyroxene, epidote, sericite, and garnet.

QUATERNARY SYSTEM

Alluvium, landslide debris, windblown material, and talus of Quaternary age obscure the bedrock in many parts of the Ute Mountains area. These materials were mapped only where they form large bodies or where they obscure bedrock contacts. The deposits were not studied closely, and no systematic attempt was made to determine their relative ages; the sequence of presentation, therefore, does not reflect age.

In the valley of McElmo Creek, thick deposits of alluvium (pl. 1) border the creek and provide soil that is intensively cultivated. The alluvial deposits are mostly of silt but include beds of sand and gravel. Alluvium also occurs in smaller stream valleys of the Ute Mountains area, and although it is similar to the alluvium along McElmo Creek, it generally contains more gravel. In the western part of the Ute Mountains much sheet-wash gravel was mapped as alluvium. Alluvium composed of reworked Mancos Shale and windblown silt is found in Montezuma Valley east of the Ute Mountains. It forms a good soil and is extensively farmed. In places, especially in McElmo Canyon, the alluvium is being rapidly removed by stream downcutting.

Stream terrace gravel (pl. 1) occurs in McElmo and in East McElmo Canyons and vicinity. The gravel rests on stream-leveled bedrock and consists of pebbles, cobbles, and boulders of both igneous rock and well-cemented sandstone. The gravel was deposited during a period of aggradation that preceded the cycle of downcutting and aggrading that gave rise to the valley-fill alluvium.

Light-brown windblown silt and very fine grained sand (pl. 1) mantle most of the mesas and pediment surfaces in the Ute Mountains area. They form an excellent porous soil capable of holding water for long periods of time and are utilized in dry farming in the higher parts of the area. The windblown material was probably derived mainly from arid areas to the southwest. The bulk of it probably accumulated during the Pleistocene Epoch, but some is still accumulating.

Fan-shaped deposits of coarse gravel occur on the south side of McElmo Canyon and in Montezuma Valley near the base of the Point Lookout Sandstone. These gravel deposits, classed as fanglomerate, were spread over rather even, steeply sloping pediment surfaces. Those of McElmo Canyon are divided into two groups on the basis of relative age. The older deposits are lithified; the younger deposits are lithified only locally and lie at the level of streams that drain the northern parts of the mountains (pl. 1). The cobbles and boulders in the fanglomerate of McElmo Canyon are mostly of igneous rock; those in the deposits in Montezuma Valley are mainly of Point Lookout Sandstone.

Thinner deposits of coarse gravel mantle gently sloping pediment surfaces that extend radially away from the mountains. These deposits were mapped as pediment gravel and no sharp line of distinction exists between them and the thicker fan-shaped deposits. In places, the gravel deposits are well cemented with caliche, but in others they are loose. Many of the gravel-covered pediments between creek beds serve as natural roads for the Ute Indians, and the gravels in the larger deposits are used extensively in highway construction.

Although, several pediment surfaces are in evidence, they were not differentiated, and the deposits were mapped as one unit.

Deposits of fine material, cobbles, boulders, and great slabs of rock that have moved downward through the combined action of gravity, water, and, in some instances, snow, were mapped as landslides (pl. 1). The largest of such deposits are on the north-facing slopes of the Ute Mountains. A large landslide deposit that lies between Black Mountain and Ute Peak (pl. 1) is of interest because in places it contains abundant material derived from the Point Lookout Sandstone, a unit that now exists only in thin remnants in the Ute Mountains. A large landslide deposit on the north slope of Mable Mountain consists mostly of Mancos Shale and boulders and cobbles of porphyry.

Bodies of talus (pl. 1) surround many of the igneous intrusive bodies. The talus is thick in the vicinity of Ute Peak, and on the west side of the peak it has streamed downward to form a rock glacier (pl. 1). On the north, east, and south sides of the peak, talus grades imperceptibly into block rubble.

In places along the flanks of the mountains, blocks of rock—principally of porphyry—have accumulated in bodies 5 to 40 feet thick, which are classed as block rubble. The rubble has a hummocky form, and in some areas may include the slumped remnants of sills or laccoliths. Water and possibly snow played major roles in the movement of the blocks. Bodies of the rubble commonly lie at considerable distances from possible source rocks. They differ from landslide deposits mainly in that they rest on gentler slopes and consist mostly of porphyry. Block rubble, landslide, and talus grade from one to another, and the contacts between them are drawn arbitrarily in many places.

IGNEOUS ROCKS

GENERAL FEATURES AND EVIDENCE FOR AGE OF IGNEOUS ACTIVITY

The igneous rocks of the Ute Mountains are members of a calc-alkalic series that ranges in composition from microgabbro through quartz monzonite. Field mapping indicates that the succession of intrusive rocks from earliest to latest was microgabbro, diorite, granodiorite, and quartz monzonite.

All the igneous bodies were intruded forcibly through or between layers of sedimentary rock. No evidence was found that the igneous rocks replaced or assimilated their wall rocks during intrusion.

The igneous rocks occur in stocks, laccoliths, bysmaliths, sills, and dikes. The dikes are radially distributed about the Black Mountain stock in the north, "The Knees" stock in the south, and an inferred concealed stock at Ute Peak.

The similarity of the intrusive forms, the geologic structure, and the types of igneous rock of each of the laccolithic mountain groups on the Colorado Plateau strongly suggests that all the laccolithic mountains formed at approximately the same time.

The igneous rocks in the Ute Mountains intrude sedimentary rocks as young as the Point Lookout Sandstone of Late Cretaceous age. This intrusion is the only direct evidence of the age of the intrusive rocks available in the Utes. Other lines of evidence (see p. 6 to 7) indicate that igneous activity in the Ute Mountains did not occur prior to the deposition of the McDermott Member of the Animas Formation of latest Cretaceous age. Shoemaker (1956, p. 162) pointed out that the only known stratigraphic evidence that may permit precise assignment of age to the laccolithic mountains is the occurrence of boulders of andesite in the McDermott. He concluded that at least some of the coarse debris in the McDermott was probably derived from the La Plata Mountains, a laccolithic group, and that some of the intrusive bodies in the La Plata Mountains are probably of latest Cretaceous age. In contrast, Hunt, Averitt, and Miller (1953, p. 212) outlined geomorphic evidence that suggests a middle Tertiary age for the Henry Mountains and thus, inferentially, for other laccolithic groups.

RELATIVE AGES OF THE INTRUSIVE ROCKS

Evidence that the microgabbro was the earliest intrusive rock and that diorite porphyry, granodiorite porphyry, and quartz monzonite porphyry are successively younger is found in both the northern and southern parts of the mountains. In the vicinity of North Black Mountain in the northern Ute Mountains, sills of microgabbro are domed upward over the underlying North Black Mountain laccolith of diorite porphyry (pl. 1). On the east side of Black Mountain, quartz monzonite porphyry has a chilled border where it is in contact with microgabbro. In the vicinity of the Horse Mountain laccolith a discordant intrusive of quartz monzonite has a chilled border where in contact with diorite porphyry (fig. 7).

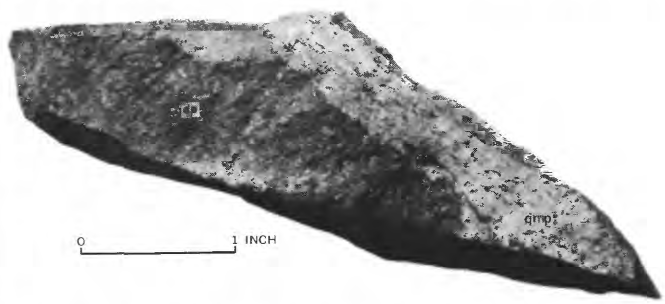


FIGURE 7.—Contact of quartz monzonite porphyry (qmp) with diorite porphyry (dp). Note that flow lineation in the quartz monzonite porphyry parallels the contact zone.

Southeast of "The Knees" stock in the southern Ute Mountains, sills of microgabbro and diorite porphyry are domed upward by a large underlying intrusive body of granodiorite porphyry.

Some of the evidence for the relative ages of the intrusive rocks, such as the doming of microgabbro by an underlying, more silicic intrusive mass, is indirect. The microgabbro might possibly have been intruded into beds that had already been domed; however, this possibility is not considered likely because (a) the microgabbro is generally more fractured than the underlying diorite porphyry and this fact suggests doming after solidification, and (b) there is evidence in some exposures that the microgabbro was altered slightly by underlying, more silicic rocks. A thin section of microgabbro from an intrusive body that overlies granodiorite porphyry southeast of "The Knees" contains significantly more quartz and calcite than a sample of microgabbro taken from an exposure several hundred yards from the granodiorite. Some of the calcite and quartz may have been introduced by hot ground water

745-807 O—65——5

when the enclosing Mancos Shale was heated by the large underlying granodiorite laccolith.

OCCURRENCE AND PETROGRAPHY

GENERAL FEATURES

In the descriptions that follow, modal analyses of several samples are given for each rock. Analyses that include modes of the groundmasses are close approximations only, owing to the dense nature of the groundmasses. The term "dense" as used in this paper implies that the grain size of the groundmass crystals averages less than 0.03 mm; "extremely dense" implies that the groundmass crystals are less than about 0.01 mm in average diameter.

The texture of the rocks varies with rock type and from one intrusive body to another. In general, the microgabbro is slightly porphyritic; the diorite is moderately porphyritic; and the granodiorite and quartz monzonite are conspicuously porphyritic. The groundmasses of the various rocks make up from 40 to 60 percent of the volume and, in general, are less dense in the mafic rocks.

MICROGABBRO

The microgabbro is an aphanitic black rock closely resembling basalt (fig. 8*A*). It occurs as sills in the northern part of the mountains and as small tongue-shaped laccoliths and thin sills in the central part of the mountains. Two varieties are recognized. One is porphyritic and contains about 10 percent hornblende and 3 to 10 percent augite in phenocrysts that are 2 to 10 mm in length. The texture of this rock varies from diabasic to trachytic. Major constituents of the groundmass are plagioclase and chlorite. The plagioclase occurs as twinned microlites that average about 0.04 by 0.1 mm and as nearly equant zoned crystals as much as 2 mm in length. Chlorite fills interstices between the plagioclase microlites, and occurs with calcite as an alteration product of augite, hornblende, and the larger crystals of plagioclase. Biotite is common as tiny books as much as 0.2 mm in length. Quartz is ubiquitous and averages about 4 percent; magnetite and apatite are the most common accessory minerals.

The other variety of microgabbro has seriate texture and contains very few crystals that exceed 1 mm in length. The rock contains about 15 percent augite and 8 percent hornblende that form the largest crystals and range in size from about 0.1 mm to slightly more than 3 mm. Plagioclase occurs as tabular zoned crystals ranging from less than 0.1 mm to about 0.6 mm, and as tiny microlites.

The larger crystals of plagioclase in both varieties of microgabbro are conspicuously zoned with centers of bytownite or calcic labradorite and outer zones of andesine. These crystals are about An_{65} in average composition, and the overall plagioclase composition is estimated to be about An_{55}.

Apatite is abundant in the microgabbro, and some crystals are as large as 1 mm in cross section.

Both varieties of microgabbro have been considerably altered. Original augite has been altered in part or completely to chlorite and calcite in all the microgabbro examined in thin section. Plagioclase and hornblende are fresh to moderately altered. The altered plagioclase commonly contains calcite, kaolin, and chlorite; the altered hornblende contains calcite and chlorite. Locally, pyrite is abundant. Vesicles filled with quartz and calcite are fairly common in the microgabbro. Modes of three samples of microgabbro are listed below.

Modes of microgabbro

[Sample 56-E-77 is porphyritic; 56-E-94 and 56-E-97 have seriate texture. For chemical analysis of 56-E-77, see table 3, sample 2]

Mineral	Field sample		
	56-E-77	56-E-94	56-E-97
Quartz	4	3	3
Plagioclase An_{55}	59	53	60
Hornblende	10	8	6
Augite	3	13	12
Magnetite	3	1	4
Relicts of early pyroxene	----------	[1] 7	----------
Calcite	[2] 7	7	6
Pyrite	----------	1	----------
Biotite	<1	----------	----------
Chlorite	14	7	9
Total	100	100	100

[1] Relicts are now filled with chlorite, limonite, and unknown green to white opaque mineral.
[2] Formed largely at the expense of pyroxene.

Locality descriptions:
56-E-77: Tongue laccoliths, northeast of "The Knees," central Ute Mountains.
56-E-94: Sill in Pine Creek, northern Ute Mountains.
56-E-97: Sill on east flank of Black Mountain, northern Ute Mountains.

DIORITE PORPHYRY

Diorite porphyry is the most abundant igneous rock in the Ute Mountains. It occurs as laccoliths, as thin sills ranging from a few feet to 100 feet in thickness, and in a few dikes. Although mapped as a single unit, the diorite porphyry is divided for purposes of description into two varieties: normal diorite porphyry and leucocratic diorite porphyry. The two varieties generally are distinguishable by differences in color caused primarily by a greater abundance of mafic minerals in the groundmass of the normal diorite porphyry, although they are petrographically gradational. Only one variety occurs in any individual intrusive body.

The normal diorite porphyry is thought to be the older. The two varieties of diorite were observed to be in contact in only one place, on the northeast side of Razorback laccolith, where leucocratic diorite porphyry of the Razorback laccolith has intruded normal diorite porphyry of the East Horse laccolith. Structural re-

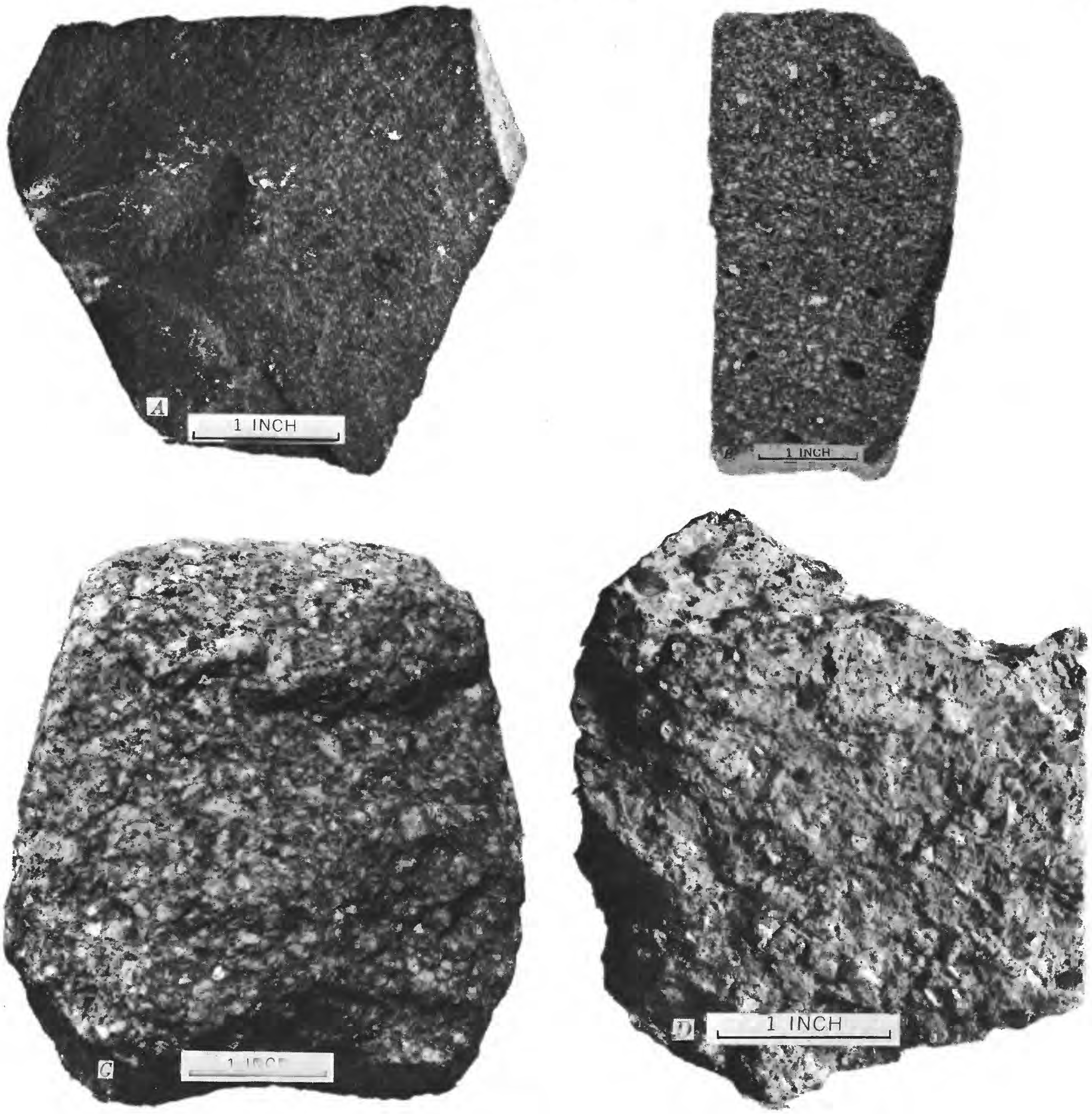


Figure 8.—Specimens of the four main types of igneous rock from the Ute Mountains. *A*, Microgabbro, nearly seriate texture. *B*, Diorite porphyry (leucocratic variety), phenocrysts are hornblende and plagioclase; note the hornblendic inclusion. *C*, Granodiorite porphyry; southern type; phenocrysts are plagioclase and pseudomorphs after hornblende, now filled with sericite, chlorite, and calcite. *D*, Quartz monzonite porphyry; phenocrysts are bipyramids of quartz, plagioclase, and pseudomorphs after hornblende.

lations elsewhere suggest indirectly that laccoliths of normal diorite porphyry have influenced the location and extent of intrusion of leucocratic diorite porphyry. Such relationships are discussed in detail in the section describing the structure of the individual intrusive masses.

The shape of laccoliths bears a general relationship to the type of diorite porphyry. The normal diorite porphyry occurs mainly as flat-topped laccoliths 200 to 500 feet thick. The leucocratic diorite porphyry occurs predominantly as thick (500 to 1,200 feet), steep-sided laccoliths that have higher ratios of vertical dimension to areal extent than laccoliths of normal diorite porphyry. Differences in viscosities of the two diorite porphyry magmas probably caused differences in the forms of the laccoliths.

NORMAL DIORITE PORPHYRY

The fresh rock is mostly greenish gray; some is yellowish gray. It weathers to a moderate yellowish brown and medium brown, and on many outcrops is stained medium to dark brown by iron. Some stain of black manganese oxide coats the older exposures.

The distinction between phenocrysts and groundmass is not microscopically sharp inasmuch as many of the rocks have a nearly seriate texture. The phenocrysts constitute about 50 percent of the volume of the rock. Of these, plagioclase is the most abundant, comprising 25 to 45 percent. The plagioclase phenocrysts are twinned and zoned and average about 0.7 by 1.0 by 2.0 mm in size. The composition ranges from calcic labradorite in the cores to oligoclase in the outer zones. The maximum difference in the anorthite content in the zones of one crystal is about 45 percent An. The phenocrysts are anhedral to euhedral in outline.

Phenocrysts of hornblende and augite constitute 12 to 17 percent of the rock and average about 14 percent. Most crystals are euhedral. The hornblende crystals average about 0.6 by 2.5 mm but generally vary considerably from these dimensions. The crystals are of the common green variety of hornblende, and in most samples have been moderately to considerably altered to magnetite, sericite, and chlorite. (See table 6.) The augite phenocrysts average about 0.3 by 1.0 mm.

Accessory minerals—magnetite, apatite, and sphene—rarely exceed 3 percent of the rock. Rare crystals of clinozoisite near the margin of one intrusive body of diorite porphyry are thought to have originated during the late magmatic stage.

A medium-gray to dark greenish-gray groundmass forms about half the volume of normal diorite porphyry and contains grains ranging in size from less than 0.01 mm to as much as 0.1 mm. Somewhat more than 70 percent of the groundmass is sodic plagioclase, anhedral quartz, and potassium feldspar. Some of the plagioclase is euhedral and a little of the potassium feldspar is subhedral. The composition of plagioclase in the groundmass can seldom be determined accurately. Small amounts of hornblende or augite normally occur in the groundmass, and chlorite is abundant. Diorite porphyry having a composition near microgabbro contains as much as 10 percent augite. Quartz is mainly interstitial and formed during a late magmatic stage. Rare rounded and embayed phenocrysts of quartz are interpreted as having formed under conditions of favorable pressure and temperature at considerable depth, although they may be partially assimilated crystals derived from a preexisting silicic rock.

LEUCOCRATIC DIORITE PORPHYRY

The leucocratic diorite porphyry crystallized from a magma slightly richer in silica and water than the magma of the normal diorite porphyry. The rock contains no pyroxene but contains more hornblende than the normal diorite porphyry. Phenocrysts constitute an average of 50 percent of the leucocratic diorite porphyry. These are zoned crystals of labradorite or calcic andesine that constitute somewhat more than 35 percent of the volume and hornblende that constitutes 10 to 20 percent. Quartz phenocrysts are rare and average less than 3 percent. The groundmass is dense or extremely dense and consists of sodic plagioclase, potassium feldspar, and quartz.

The leucocratic diorite porphyry is megascopically very similar to the granodiorite porphyry of Ute Peak but differs from the rock at Ute Peak in its lower content of potassium feldspar and its lack of pyroxene. A specimen of the leucocratic diorite porphyry is shown on figure 8*B*.

Modes of diorite porphyry

[See table 3 for chemical analyses of 56–E–42 (sample 5), 56–E–33 (sample 6)]

Constituent	Field sample				
	Normal diorite porphyry			Leucocratic diorite porphyry	
	55–E–47	56–E–42	56–E–37	56–E–33	H–539
Quartz	Tr.	1.6	4.2	0.4	2.6
Potassium feldspar	--------	4.8	3.0	--------	--------
Plagioclase	38.1	60.4	68.6	28.2	25.6
Hornblende	4.3	7.0	7.2	17.0	19.2
Augite	8.5	[1] 9.4	5.0	--------	--------
Epidote	--------	--------	--------	--------	--------
Magnetite	4.0	2.2	.4	.4	1.7
Apatite	.3	Tr.	.2	.6	--------
Alteration products:					
Chlorite	12.4	12.8	8.6	9.4	1.0
Sericite (after hornblende)	--------	--------	--------	--------	.3
Calcite	--------	1.8	2.6	--------	1.2
Kaolinite	--------	--------	--------	--------	.2
Sericite	--------	--------	.2	--------	.6
Groundmass [2]	32.4	--------	--------	44.0	47.6
Total	100.0	100.0	100.0	100.0	100.0

[1] Augite occurs as fine-grained prisms.
[2] Groundmass consists mainly of sodic plagioclase, quartz, and potassium feldspar. Although the groundmasses of 56–E–42 and of 56–E–37 were counted, the modes as shown are considered to be approximations only.

Locality descriptions:
55–E–47: South side Yucca laccolith.
56–E–42: Unnamed laccolith in Yucca cluster of laccoliths, SE¼ sec. 33, T. 35 N., R. 18 W.
56–E–37: Southwest part of unnamed laccolith in the West Toe cluster, SE¼ unsurveyed sec. 4, T. 34 N., R. 18 W.
56–E–33: West side Pack Trail laccolith.
H–539: West end Horse laccolith.

GRANODIORITE PORPHYRY

For mapping purposes, three distinctly different rocks have been grouped together as granodiorite porphyry. Because the three rocks are localized geographically within the Ute Mountains, they will be referred to as the southern, central, and northern types.

The southern type (fig. 13*C*) is a light-gray rock that forms laccoliths, bysmaliths, dikes, and a stock in the southern and south-central parts of the mountains. It is characterized by phenocrysts of zoned plagioclase in equant grains as much as 10 mm across, and by pseudomorphic aggregates of secondary minerals that indicate the former presence of phenocrysts of hornblende. The plagioclase is estimated to average about An_{40}. The pseudomorphs after hornblende are filled with sericite, chlorite, and calcite. Quartz phenocrysts are rare. An extremely dense groundmass constitutes 50 percent of the volume of this rock. Although the groundmass cannot be effectively examined microscopically, staining by sodium cobaltinitrite reveals the presence of abundant potassium feldspar, and norms have as much as 16 percent potassium feldspar. (See p. 36 to 37.) Sodic plagioclase and quartz are the other principal constituents of the groundmass.

The central type of grandodiorite porphyry is a light-gray rock that occurs only in the Mushroom laccolith. It contains abundant fine-grained crystals of quartz as much as 0.5 mm in diameter. This rock was mapped as tonalite porphyry in the field but was later placed with the granodiorite on the basis of total K_2O and Na_2O. This rock is similar to the southern type of granodiorite in that andesine (An_{40}) and pseudomorphs after hornblende are the most common phenocrysts, although the andesine crystals are much smaller in the central type and rarely exceed 4 mm in diameter. The hornblende pseudomorphs are filled with chlorite, sericite, calcite, and iron ore.

Most of the plagioclase in the central and southern types of granodiorite has been altered in part or completely to sericite, calcite, and chlorite. In the most intensely altered rocks, pseudomorphs after plagioclase contain fine-grained quartz or chalcedony in addition to the minerals listed above, and the hornblende pseudomorphs contain partly opaque material that is probably a mixture of clay, sericite, chlorite, and calcite. Pyrite is locally abundant. Epidote and garnet are common in granodiorite of the southern type in the vicinity of "The Knees" stock (south-central mountains).

The northern type of granodiorite porphyry, called hornblende granodiorite porphyry, occurs in and adjacent to the Black Mountain stock and in the Ute Peak bysmalith. A specimen of this rock is shown on figure 9. The rock closely resembles the diorite porphyry in hand specimen but contains more fine-grained potassium feldspar. The potassium feldspar, sanidine, is confined to the groundmass, which is coarser than in the other types of granodiorite porphyry and can be analyzed fairly accurately with the microscope. In addition to sanidine, the groundmass consists mainly of sodic plagioclase and quartz. Phenocrysts in this rock include plagioclase, hornblende, augite, magnetite, and sparse rounded crystals of zircon. The plagioclase occurs as equant crystals (0.5–2.5 mm) that are conspicuously zoned from calcic labradorite in the cores to sodic andesine and oligoclase in the outer zones. The average plagioclase (phenocrysts and groundmass) is estimated to be about An_{35}.

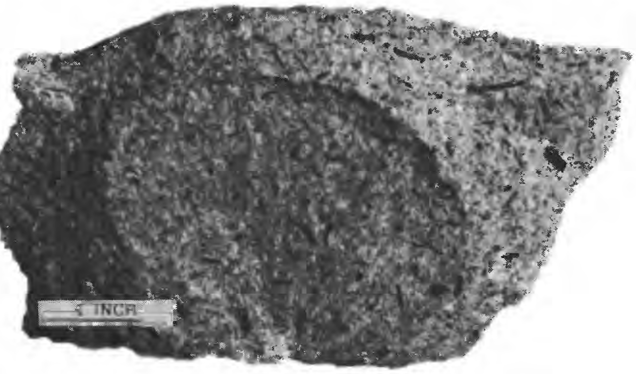


FIGURE 9.—Specimen of hornblende granodiorite porphyry from Ute Peak.

In contrast to the generally altered character of the granodiorite porphyry in the central and southern parts of the mountains, the hornblende granodiorite porphyry of Ute Peak and Black Mountain is relatively fresh. Many of the plagioclase crystals are clear, and some of the hornblende is fresh except for slight alteration to pyroxene and magnetite along crystal borders.

Modes of the three types of granodiorite porphyry are shown below.

Modes, in percent, of granodiorite porphyry

[See table 3 for chemical analysis of 56-E-82 (sample 13)]

Constituent	Field sample		
	Southern type	Central type	Northern type (hornblende granodiorite)
	56-E-140	56-E-82	55-E-16
Quartz	1.4	7.2	4.2
Plagioclase	34.8	37.2	65.6
Potassium feldspar			12.8
Hornblende	[1] 8.6	[1] 9.8	8.2
Augite	Tr.		2.0
Magnetite	.8	1.6	3.6
Apatite	Tr.	Tr.	.2
Zircon			Tr.
Biotite			.2
Chlorite			1.8
Calcite			1.4
Sericite		2.8	
Groundmass	54.4	41.4	
Total	100.0	100.0	100.0

[1] Pseudomorphs after hornblende are filled with chlorite, sericite, and calcite.
Locality descriptions:
56-E-140: Dike north of "The Knees" stock.
56-E-82: Mushroom laccolith.
55-E-16: Approximately 1,500 ft. below top of Ute Peak, east side.

QUARTZ MONZONITE PORPHYRY

The name quartz monzonite porphyry is applied to rocks of two types in the Ute Mountains. One type is characterized by pyrogenic biotite phenocrysts and occurs only in the northern mountains in the vicinity of Black Mountain. The other type contains mica only as secondary crystals in pseudomorphs after hornblende. This type occurs only in the southern part of the mountains. The two types will be referred to as the northern and southern types of quartz monzonite porphyry.

The northern type of quartz monzonite porphyry is light blue gray where unaltered and pale green to greenish white where altered. It contains phenocrysts of quartz, plagioclase, and biotite that make up about 50 percent of the volume of the rock. Quartz phenocrysts average about 9 percent occurring as rounded bipyramids that range in diameter from about 0.1 to 1 mm and average about 0.4 mm. Tabular or equant euhedral crystals of plagioclase that reach 2 mm in length make up from 30 to 35 percent of the rock, and biotite occurring as books makes up 3 to 9 percent. The plagioclase crystals are conspicuously zoned with cores of labradorite or andesine and outer zones of oligoclase or albite. The books of biotite range from about 0.1 to 1.5 mm and average about 0.4 mm. Magnetite usually exceeds 1 percent of the volume and occurs as subhedral grains that average about 0.2 mm in diameter.

The groundmass of the northern type of quartz monzonite is extremely dense; most of the grains average about 0.01 mm in diameter. Although the amount of potassium feldspar in the groundmass cannot be accurately determined optically, staining of thin sections with sodium cobaltinitrite reveals that potassium feldspar constitutes more than 10 percent of the rock. The anorthite content of the fine-grained plagioclase in the groundmass could not be determined with the microscope, but chemical analyses of the rock indicate a high content of Na_2O, and the plagioclase in the groundmass is probably albite.

The rock is generally quite altered; biotite crystals are wholly or partly altered to chlorite and plagioclase crystals wholly or partly altered to calcite, kaolinite, and chlorite. Epidote is common (as much as 1 percent) as subhedral grains 0.15 mm in length.

The southern type of quartz monzonite is light blue gray where unaltered and light tan where altered. It differs from the northern type of quartz monzonite in grain size and texture, and is petrographically gradational with the southern type of granodiorite porphyry, which it resembles. In the field, it is distinguished from the southern type of granodiorite by the abundance of quartz phenocrysts. Quartz, plagioclase, and pseudomorphs after hornblende are the most abundant phenocrysts in the quartz monzonite, and make up about 45 percent of the volume. Quartz phenocrysts average about 4 percent, plagioclase about 35 percent, and pseudomorphs after hornblende about 3 percent. Although quartz phenocrysts comprise a relatively small fraction of the rock, they are the most conspicuous crystals owing to the fact that they are never altered and are highly resistant to erosion. In nearly all exposures the quartz crystals (as much as 5 mm in diameter) protrude from the surface of the rock (fig. 8*D*). Plagioclase phenocrysts are commonly 3 by 4 by 5 mm (rarely as much as 10 mm in length) and are conspicuously zoned from cores of labradorite or andesine to outer layers of oligoclase or albite. They are commonly altered to calcite, kaolinite, chlorite, albite, and sericite. Pseudomorphs after hornblende are filled with sericite, chlorite, and calcite.

Tiny phenocrysts of epidote and apatite are common in the southern type of quartz monzonite. Strongly zoned yellow-green, distinctly pleochroic crystals of epidote are as much as 0.6 mm in length. Apatite crystals as much as 0.5 mm in length are of euhedral tabular habit, and are commonly clear to slightly brownish in thin section. The brown rarely penetrates the entire crystal, but is an ubiquitous feature of the apatite in both the quartz monzonite and granodiorite of the southern type. Indices of refraction of this brownish apatite range from 1.616 to 1.621. Magnetite is extremely rare in the southern type of quartz monzonite. This scarcity is probably due to alteration because, where magnetite is present, it is always partly altered to limonite or hematite or both.

The groundmass of the southern type of quartz monzonite, as with the northern type, is extremely dense. Staining of thin sections with sodium cobaltinitrite revealed abundant potassium feldspar in the groundmass, and a comparison of modal analyses of the phenocrysts with normative minerals of the rock suggests that the groundmass is also rich in albite and quartz.

LAMPROPHYRE

A lamprophyre, spessartite, is found in the extreme western part of the Ute Mountains in the vicinity of Yucca laccolith, and in the northern part at Black Mountain. The rock forms sills and short dikes that intrude Mancos Shale in the western exposures. At Black Mountain the spessartite appears to intrude granodiorite porphyry, although the relations are obscure because the contacts between the rocks are not exposed. A planar structure or rock cleavage in the spessartite dips 22° E., in contrast with the steeply dipping and plunging granodiorite porphyry.

The rock exposed in the western part of the mountains is dark brownish gray and is conspicuously porphyritic; it contains large phenocrysts of pyroxene and hornblende that commonly exceed 10 mm in length.

Modes, in percent, of quartz monzonite porphyry

[See table 3 for chemical analysis of samples 56-E-92 (sample 15), H-465 (sample 16)]

Constituent	Field sample			
	Northern type		Southern type	
	56-E-92 (altered)	56-E-101	H-465	56-E-13
Quartz	7.8	9.4	3.8	3.5
Potassium feldspar	----------	----------	----------	----------
Plagioclase	[1] 31.8	30.6	35.6	31.8
Biotite	1.8	[2] 8.8	----------	----------
Sericite (after hornblende)	----------	----------	----------	.9
Epidote	----------	.8	.1	----------
Magnetite	.4	1.6	----------	----------
Apatite	Tr.	Tr.	.1	.1
Alteration products:				
Chlorite (after hornblende or biotite)	1.2	----------	4.6	2.2
Calcite	----------	----------	----------	2.6
Kaolinite	----------	----------	.2	2.3
Sericite	2.4	----------	.1	----------
Groundmass	54.6	48.8	55.5	56.6
Total	100.0	100.0	100.0	100.0

[1] Largely altered to calcite and chlorite.
[2] Partly altered to chlorite.

Locality descriptions:
56-E-92: Cottonwood Creek vicinity, east side Black Mountain.
56-E-101: Black Mountain (central part).
H-465: West side Banded laccolith.
56-E-13: Sentinel Peak dome.

A zeolite (thomsonite) fills cavities as much as 20 mm in diameter and adds to the porphyritic appearance of the rock. The pyroxene was determined to be common augite with a 2V of $54° \pm 1°$ and N_y of 1.70.

The groundmass of the rock is almost entirely plagioclase and chlorite but contains sparse amounts of biotite, potassium feldspar, and zeolites. The average composition of the plagioclase is andesine which occurs as tabular crystals that range from 0.2 to 1 mm in length. Biotite is common as small books as much as 1 mm in length and as tiny shreds. Potassium feldspar occurs as small anhedral crystals that average less than 1 mm in diameter and as an alteration product of plagioclase. Analcime is abundant in small cavities and as a replacement product of plagioclase. The analcime in the cavities shows very low birefringence and pseudopolysynthetic twinning. Other zeolites are heulandite, stilbite, natrolite, and mesolite. Magnetite is abundant, making up from 2 to 4 percent of the rock, and apatite is a ubiquitous accessory.

The rock exposed at Black Mountain has nearly seriate texture except for large hornblende crystals as much as 30 mm in length. The rock is dark brownish gray, and, in addition to hornblende, contains plagioclase, augite, actinolite, and chlorite. Plagioclase occurs as tabular subhedral crystals that range from about 0.2 to 1.5 mm across. The plagioclase is relatively unaltered, and extinction angles indicate an average composition of sodic labradorite for the larger crystals and calcic andesine for the smaller crystals; the average composition is probably calcic andesine. The central parts of a few crystals of plagioclase have been altered to potassium feldspar. Augite is abundant as euhedral crystals about 2 mm in length, most of which are rimmed with actinolite. Chlorite with actinolite occurs in sheaves and radiating fibrous groups 0.1 to 0.3 mm in diameter and formed largely from fine-grained augite. Biotite occurs as books that range in size from 0.1 mm to more than 4 mm. A few crystals are partly altered to chlorite. Magnetite and pyrite are common accessory minerals and two zeolites, thomsonite and chabazite(?), coat fractures in the rock.

In the field the spessartite can easily be mistaken for microgabbro, but the absence of quartz in the spessartite and the large crystals of hornblende or augite are distinctive. Two modes of spessartite follow.

Modes, in percent, of spessartite

[See table 3 for chemical analysis of sample 55-E-46 (sample 1)]

Mineral	Field sample	
	55-E-46	56-E-104
Andesine	[1] 43	36
Augite	17	9
Hornblende	3	10
Potassium feldspar	1	1
Biotite	5	6
Magnetite	2	3
Actinolite (after augite)	----------	19
Chlorite	24	16
Calcite	2	----------
Analcime	[2] 2	----------
Thomsonite	1	----------
Total	100	100

[1] Largely altered to kaolin and analcime.
[2] This value does not include analcime replacing parts of plagioclase crystals.

Locality descriptions:
55-E-46: Yucca laccolith.
56-E-104: Black Mountain.

INCLUSIONS

Inclusions are common in the igneous rocks of the Ute Mountains. More than 90 percent are rich in hornblende, although a few contain none. Xenoliths derived mostly from Mesozoic sedimentary rocks are ubiquitous but rare. They are mostly hornfels of Mancos Shale and silicated sandstones derived from the Dakota and Burro Canyon. Most of the xenoliths are less than a foot in diameter although a few are large as a house. Fragments of granophyric granite are fairly common as inclusions in the northern mountains, especially in the Pack Trail laccolith (pl. 1).

The granitic inclusions superficially resemble the Precambrian granite observed in the Gulf Oil Co. Fulks 1 drilled in the NW¼NW¼ sec. 27, T. 37 N., R. 17 W., 10.5 miles north-northeast of Ute Peak but differ from it in several important ways. A characteristic feature of the inclusions is the occurrence of large grains of orthoclase intergrown with crystals of quartz in typical granophyric texture. The texture of the granite in the Gulf well, on the other hand, is hypautomorphic-granular. Most of the inclusions are nearly free of mafic minerals, whereas the granite in the Gulf well is rich in mafic minerals. A few inclusions contain biotite and(or) hornblende, but these show a strong gneissic fabric. According to Zabel (1955, p. 136) and Phillip Katich (oral commun., 1958), structureless granite has been the only Precambrian rock penetrated by the drill in the Ute Mountains region. Thus the granitic inclusions in the Ute Mountains evidently were not of local origin but were, perhaps, brought to the surface from considerable depth. A few inclusions contain both granite and hornblende-rich layers (fig. 10*A*), and the possibility exists that both the granite and the hornblende-rich inclusions were derived from the same substratum.

The hornblende-rich inclusions are found in all the igneous rocks in the Ute Mountains, but are most abundant in the diorite, where in some outcrops they comprise as much as 5 percent of the volume of the rock. They range in diameter from less than an inch to more than a foot. Although most of the inclusions have sharp contacts (fig. 10) with the enclosing igneous host rock, a few have gradational contacts—that is, the hornblende becomes less abundant outward from the central part of the inclusion. Some of the hornblendic inclusions are nearly monomineralic and appear structureless; others have a distinct gneissic or schistose texture and contain other minerals in large proportions.

Modes of three hornblende-rich inclusions and a granite inclusion are shown below.

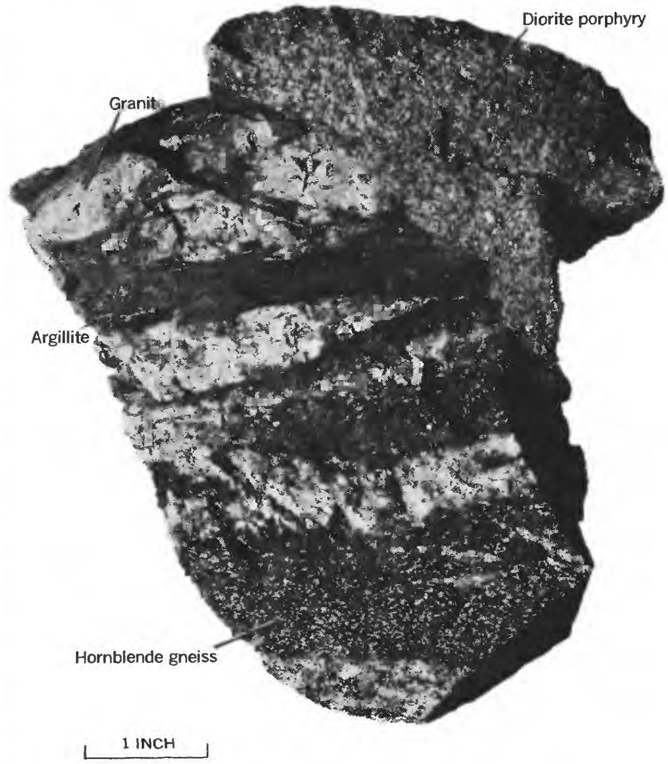
Modes, in percent, of inclusions

[Chemical analyses are shown in table 3]

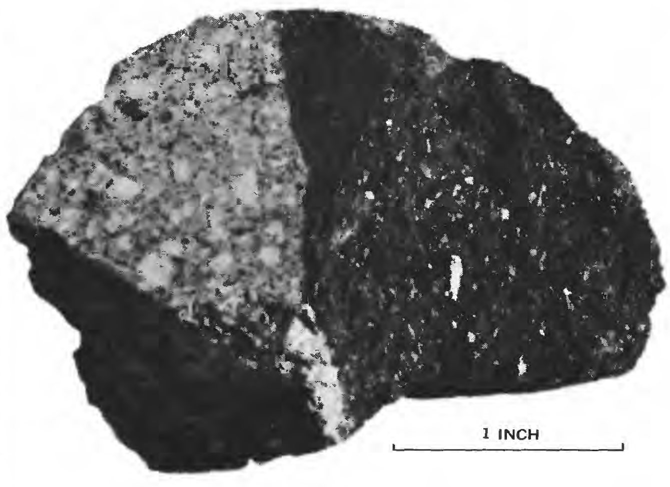
Mineral	Field sample			
	56–E–223	EMS–64–52	56–E–105	EMS–101–52 (granite)
Hornblende	90.2	39.5	44.2	
Augite			32.5	
Plagioclase		[1] 24.2	4.4	[2] 27.8
Potassium feldspar		3.7		30.6
Quartz		2.8	1.3	40.0
Biotite	[3] 3.4	[3] 8.0		.6
Apatite	.2	1.5	.6	
Magnetite	4.8	1.5	9.7	.2
Sphene		.8		
Pyrite	Tr.			
Calcite	.2	3.5		
Epidote		5.7		
Chlorite	1.2	6.5	7.3	
Hematite	Tr.	2.3		
Garnet				.8
Total	100.0	100.0	100.0	100.0

[1] An_{50}.
[2] An_{10}.
[3] Includes yellow-brown chlorite.

Locality descriptions:
56–E–223: Sentinel Peak bysmalith.
EMS–64–52: Sentinel Peak bysmalith. Collected by E. M. Shoemaker.
56–E–105: Black Mountain stock.
EMS–101–52: Black Mountain stock. Collected by E. M. Shoemaker.



A



B

FIGURE 10.—Inclusions in intrusive igneous rocks of the Ute Mountains. *A*, Metasediment composed of argillite and hornblende gneiss injected with granite. *B*, Hornblende-rich inclusion composed almost entirely of hornblende. Granodiorite is the enclosing host rock.

Samples 56–E–223 and EMS–64–52 are inclusions from the Sentinel Peak bysmalith, which consists of granodiorite whose mafic minerals are all pseudomorphous after hornblende. Both samples contain biotite, but neither they nor the host rock contains pyroxene. The hornblende in sample 56–E–223 has been partly altered to yellow-brown chlorite and green chlorite near the contact with the granodiorite porphyry. This alteration probably occurred at the same time as that of the phenocrysts of hornblende in the host rock.

Magnetite is abundant in this inclusion, and some grains contain cores of pyrite.

Sample EMS–64–52 consists of large crystals of hornblende and epidote in a matrix of plagioclase, potassium feldspar, biotite, and quartz. The plagioclase is more calcic than that of the host rock, averaging about An_{50} in composition, and is not zoned. The epidote crystals are conspicuously zoned and are commonly engulfed by single large crystals of plagioclase.

Sample 56–E–105 has distinct gneissic structure expressed by alternating layers of light and dark minerals. Augite is nearly as abundant as hornblende in the inclusion. Within the dark layers, laminae consisting almost entirely of augite alternate with laminae composed almost entirely of hornblende. Apatite is common in this inclusion and is much more abundant near the contact with the host rock.

ALTERATION

Four types of alteration other than baking effects near contacts have been observed in or near intrusive bodies. They are: (a) deuteric alteration of the central parts of laccoliths, (b) hydrothermal alteration at Mable Mountain, (c) pyritization in the vicinity of igneous contacts with Mancos Shale, and (d) hydrothermal or hot-spring alteration associated with the formation of breccia pipes in the Yucca cluster of intrusives.

DEUTERIC ALTERATION

The central parts of many laccoliths have been intensely altered by deuteric action. The alteration is a direct result of the partial sealing in of residual liquids in the interior of an intrusive mass.

In the altered rock, phenocrysts of calcic plagioclase have been partly replaced by more sodic plagioclase and sericite, calcite, and minor chlorite and kaolinite. Hornblende has been altered to sericite, chlorite, and magnetite, and pyroxene to chlorite. The groundmass in the altered rock generally contains more chlorite, sericite, kaolinite, and quartz than in the fresh rock.

The Sundance laccolith, the Three Forks laccolith, and several laccoliths in the Yucca cluster (pl. 1) have altered central parts that are well exposed.

HYDROTHERMAL ALTERATION AT MABLE MOUNTAIN

The rocks at Mable Mountain are fractured along a northeast-trending zone that cuts through the central part of the mountain and appears to be an upward extension of the zone along which the Ute Creek dike was intruded (pl. 1). Pyrite occurs in veins in the fracture or shear zone and as discrete crystals in the rocks for a considerable distance on either side of the fracture zone. At the surface the pyrite is altered to red limonite

Magnetite is abundant in this inclusion, and some grains contain cores of pyrite.

In addition to being pyritized, the rocks at Mable Mountain have been slightly argillized and slightly sericitized. Thin sections of altered diorite porphyry reveal that plagioclase phenocrysts have been altered to clay, sericite, and calcite, and phenocrysts of hornblende to chlorite, calcite, pyrite, and magnetite.

PYRITIZATION IN THE VICINITY OF IGNEOUS CONTACTS

Exposures of contacts of diorite porphyry and Mancos Shale commonly reveal disseminated crystals and irregular masses of pyrite in both the porphyry and the shale as much as 20 feet from the contacts. Because the shale is gypsiferous, it may have furnished most of the sulfur for the pyrite.

HYDROTHERMAL (HOT-SPRING) ALTERATION ASSOCIATED WITH BRECCIA PIPES

Rocks in and above nearly circular breccia pipes in the Mancos Shale in the extreme western part of the mountains (in or adjacent to sec. 31, T. 35 N., R. 18 W.) have been altered by hydrothermal solutions of the hot-spring type. Above the pipes, a laccolith composed of diorite porphyry and a sill of lamprophyre have been intensely fractured and impregnated with travertine. The travertine was apparently deposited by calcium carbonate-bearing hot water that rose along the pipes. Pieces of diorite porphyry fill the central parts of some of the pipes and in places are argillized and nearly white. Mancos Shale within the pipes is light gray green to light tan in contrast to its normal dark-gray to black color. The breccia pipes are discussed further on pages 59 to 60.

PETROLOGY

CHEMICAL COMPOSITION OF THE IGNEOUS ROCKS

Chemical analyses of 16 igneous rocks and of 2 inclusions are shown in table 3. All the analyses, with the exception of two from Cross (1894), were made by methods described by Shapiro and Brannock (1956). The norms were computed by using the direct method described by Wahlstrom (1947, p. 235–237). In this method, diopside is not computed and excess CaO is allotted to wollastonite. MgO and FeO are allotted to enstatite, ferrosilite (iron hypersthene), and magnetite.

Sample 1 in table 3 is of the porphyritic spessartite lamprophyre. This rock contains the least silica and alumina of any rock in the Ute Mountains and is completely without quartz. The norm indicates that the rock is undersaturated in silica. Olivine (forsterite) is computed in the norm, although it is not actually found in the rock. The principal mafic minerals,

745-807 O-65—6

TABLE 3.—*Chemical analyses and norms of igneous rocks from the Ute Mountains, Colo.*

[Analyses, in percent, by P. L. D. Elmore, S. D. Botts, and K. E. White (samples 1, 2, 5, 6, 13, 15); Elmore, Botts, and M. D. Mack (samples 3, 4, 12); H. F. Phillips, Elmore, and White (samples 7, 11, 14, 17, 18); W. F. Hillebrand (samples 8, 10); Elmore and Botts (samples 9, 16)]

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Field No.	56-E-46A	56-E-77	55-E-48A	55-E-57A	56-E-42	56-E-33	EMS-96-52	--------	H-515	--------	EMS-65-52	56-E-40	56-E-82	EMS-94-52	56-E-92	H465-1	EMS-101-52	EMS-64-52
Laboratory No.	148755	148758	150490	150489	148757	148756	81653	--------	150061	--------	77081	150492	148759	81651	148760	150060	81654	77080
Analyses																		
SiO_2	48.8	50.0	55.3	55.9	56.8	58.6	57.4	59.42	61.1	62.65	62.6	64.6	65.2	68.4	68.7	68.9	76.0	40.8
Al_2O_3	15.5	17.3	16.7	17.2	16.7	17.4	16.7	16.79	16.9	16.68	17.6	16.5	16.8	16.7	17.1	17.4	14.0	14.4
Fe_2O_3	4.8	2.9	5.0	4.8	3.1	2.6	.9	3.23	3.8	2.35	1.9	1.3	2.3	1.3	1.4	1.3	.5	5.3
FeO	5.7	5.8	1.8	2.8	3.8	4.4	5.5	3.29	2.3	2.63	2.1	1.8	1.1	.78	.64	.43	.29	10.0
MgO	5.3	3.4	2.5	3.1	3.1	3.0	2.2	2.24	2.1	1.43	1.1	1.0	1.0	.36	.78	.54	.07	8.1
CaO	8.5	9.0	6.0	6.4	6.5	4.8	5.8	5.57	4.7	4.96	4.3	3.7	3.7	1.8	1.7	2.3	1.3	11.3
Na_2O	3.8	3.3	4.0	3.9	3.7	4.4	4.2	4.15	4.0	4.45	5.1	3.7	4.0	6.0	4.0	5.4	3.6	2.3
K_2O	1.9	1.1	1.9	2.0	2.1	2.1	2.1	2.82	2.9	2.75	2.0	2.7	2.4	2.8	3.6	3.0	4.7	1.1
TiO_2	1.2	.85	.72	.78	.72	.68	.60	.68	.66	.42	.35	.30	.32	.17	.20	.18	.04	1.4
P_2O_5	.42	.49	.36	.37	.29	.30	.34	.35	.31	.28	.19	.10	.16	.10	.11	.08	.00	.76
MnO	.17	.16	.15	.16	.12	.12	.14	.13	.09	.16	.07	.12	.08	.06	.06	.05	.02	.23
H_2O	3.7	2.8	4.1	2.2	2.6	1.6	4.0	1.06	1.4	.93	1.5	1.9	1.6	1.4	2.0	1.0	.20	2.0
CO_2	.46	2.8	.61	.20	.58	.05	.20	.44	.10	--------	1.3	1.5	1.2	.34	.12	.13	.05	1.1
Total	100.25	99.90	99.14	99.81	100.11	100.05	100.08	100.17	100.36	99.69	100.11	99.22	99.86	100.21	100.41	100.71	100.77	98.79
Norms																		
Q	0.0	7.6	11.2	9.7	11.1	9.2	8.0	11.0	15.0	14.1	17.7	26.7	27.0	19.7	26.9	21.0	--------	--------
or	11.2	6.5	11.2	11.9	12.4	12.4	12.4	16.7	17.1	16.3	11.8	16.0	14.2	16.6	21.3	17.7	--------	--------
ab	32.1	27.9	33.8	33.0	31.3	37.2	35.5	35.1	33.8	37.6	43.1	31.3	33.8	50.7	33.8	45.7	--------	--------
an	19.9	24.4	21.9	23.4	22.4	20.9	20.4	18.7	19.4	17.2	11.9	8.5	10.0	6.0	7.5	10.0	--------	--------
C	0	1.7	0	0	0	.2	0	0	0	0	2.6	4.3	3.9	1.5	3.9	1.6	--------	--------
ol	9.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	--------	--------
en	0	8.5	6.3	7.8	7.8	7.5	5.5	5.5	5.3	3.6	2.8	2.5	2.5	.9	2.0	1.4	--------	--------
fs	4.9	7.3	0	.2	3.5	5.1	8.4	2.5	0	2.5	1.8	2.0	0	.2	0	0	--------	--------
mt	6.9	4.2	4.5	7.0	4.5	3.8	1.3	4.7	5.5	3.4	2.8	1.9	3.3	1.9	2.0	1.9	--------	--------
hm	0	0	.5	0	0	0	0	0	0	0	0	0	0	0	0	0	--------	--------
il	2.2	1.6	1.4	1.5	1.4	1.3	1.1	1.3	1.2	.8	.7	.6	.6	.3	.4	.3	--------	--------
cc	1.0	6.4	1.4	.5	1.3	0	.5	1.0	.2	0	3.0	3.4	2.7	.8	.3	.3	--------	--------
ap	.9	1.1	.8	.8	.6	.7	.7	.8	.7	.6	.4	.2	.4	.2	.2	.2	--------	--------
wo	9.3	0	.8	2.1	.6	0	2.1	2.2	.6	2.9	0	0	0	0	0	0	--------	--------

Sample material	Locality
1. Spessartite	Vicinity of Yucca cluster.
2. Microgabbro	The Tongue laccolith.
3. Diorite porphyry	Yucca cluster.
4. Do	Do.
5. Do	Do.
6. Do	Pack Trail laccolith.
7. Do	Flat laccolith.
8. Granodiorite porphyry.	Ute Peak (Cross, 1894).
9. Granodiorite porphyry.	Ute Peak.
10. Do	"The Knees" (Cross, 1894).
11. Do	Sentinel Peak (vicinity of "The Knees").
12. Do (altered)	Mushroom laccolith.
13. Do	Do.
14. Quartz monzonite porphyry.	Vicinity of Sentinel Peak.
15. Quartz monzonite porphyry.	Vicinity of Black Mountain.
16. Do	Banded laccolith.
17. Granophyre inclusion.	Vicinity of Black Mountain.
18. Hornblendite inclusion.	Sentinel Peak.

chlorite, augite, and hornblende presumably contain all the magnesium in the rock. Only about 1 percent potassium feldspar was observed in thin section whereas there is 11 percent of normative potassium feldspar. The difference is in part due to abundant modal biotite (not calculated in the norm), and probably in part to $KAlSi_3O_8$ in solid solution in the plagioclase. The rock is undersaturated with respect to alumina and, as a consequence, abundant wollastonite appears in the norm.

Sample 2 is of the porphyritic microgabbro. The rock is moderately altered and contains about 7 percent calcite. The microgabbro is quite low in magnesium relative to gabbro from other parts of the United States (Clarke, 1924, p. 465). This low value reflects the lack of olivine and the paucity of pyroxene in the porphyritic variety of microgabbro.

Samples 3–7 are of diorite porphyry. In general, the analyses show more Na_2O than inferred from the mode and indicate a considerably higher content of sodic plagioclase than in the microgabbro. The K_2O content in the five samples of diorite porphyry analyzed is nearly constant at about 2 percent. This content is nearly twice the K_2O in the microgabbro, and the difference is expressed in thin section by abundant small crystals of potassium feldspar in the groundmasses of all the diorite porphyry samples.

Six samples, 8–13, are of granodiorite porphyry and include the southern type (10, 11), the central type (12, 13), and the northern type (8, 9).

The granodiorite is richer in SiO_2, K_2O, and Na_2O than the diorite and has slightly less MgO, CaO, and total Fe. The K_2O is fairly uniform except in sample 11, which apparently contains much albite and an abnormally small amount of potassium feldspar.

The central type of granodiorite porphyry is the most silicic of the granodiorite and is the poorest in total iron and magnesia. This type is intermediate between granodiorite and quartz monzonite.

The northern type of granodiorite (hornblende granodiorite of Ute Peak and Black Mountain) has the coarsest groundmass. An approximate mode agrees well with the norm except that there is 11 to 15 percent of normative quartz and only 4 to 5 percent of modal quartz. This difference is probably due entirely to errors in identifying the minerals of the groundmass.

Samples 14–16 are of quartz monzonite porphyry. These rocks are all characterized by conspicuous phenocrysts of quartz and by an extremely dense groundmass. The extremely fine grain of the groundmass and the high content of Na_2O in these rocks create a problem as to rock name. The norms indicate a greater abundance of albite than in the granodiorite but, in general, about the same amount of orthoclase. The rocks could have been included with the granodiorite, but their quartz phenocrysts and low color indices make them separable in the field, and their high silica content, total alkali metal content, and low calcium, iron, and magnesium content make them easily separable chemically from the granodiorite. The name quartz monzonite is believed justified on the basis of total alkali feldspar (albite+potassium feldspar). The chemical analyses indicate an average of about 68 percent silica, which is approximately 5 percent more than the average silica for granodiorite. The samples of quartz monzonite porphyry contain more Na_2O plus K_2O than the granodiorite, less calcium, and markedly less total iron and magnesium. The K_2O content averages about 3 percent.

VARIATION DIAGRAMS

The weight percentages of six major oxides in the analyses were plotted against the percentage of silica. (See fig. 11.) Ferric iron was recomputed to ferrous iron for each analysis and is shown with the reported ferrous iron. The resulting total iron eliminates the erratic though somewhat mutually compensating variations of the two iron oxides.

The diagrams clearly illustrate the nearly constant alumina content of the rocks (excluding the lamprophyre), the steep decline of total iron, magnesia, and lime from high values in the microgabbro to low values in the quartz monzonite, and the gentle rise of Na_2O+K_2O with increasing silica. The curve for the sum of the two alkalies shows a pronounced reciprocal relationship with lime. This relation is a reflection of the increased amount of sodic plagioclase and potassium feldspar in the more silicic rocks.

The alkali-lime index (Peacock, 1931) provides a means of comparing igneous rocks throughout a region or district. The alkali-lime index for the igneous rocks of the Ute Mountains is 59 (fig. 17). According to Peacock's classification, these rocks are within the calc-

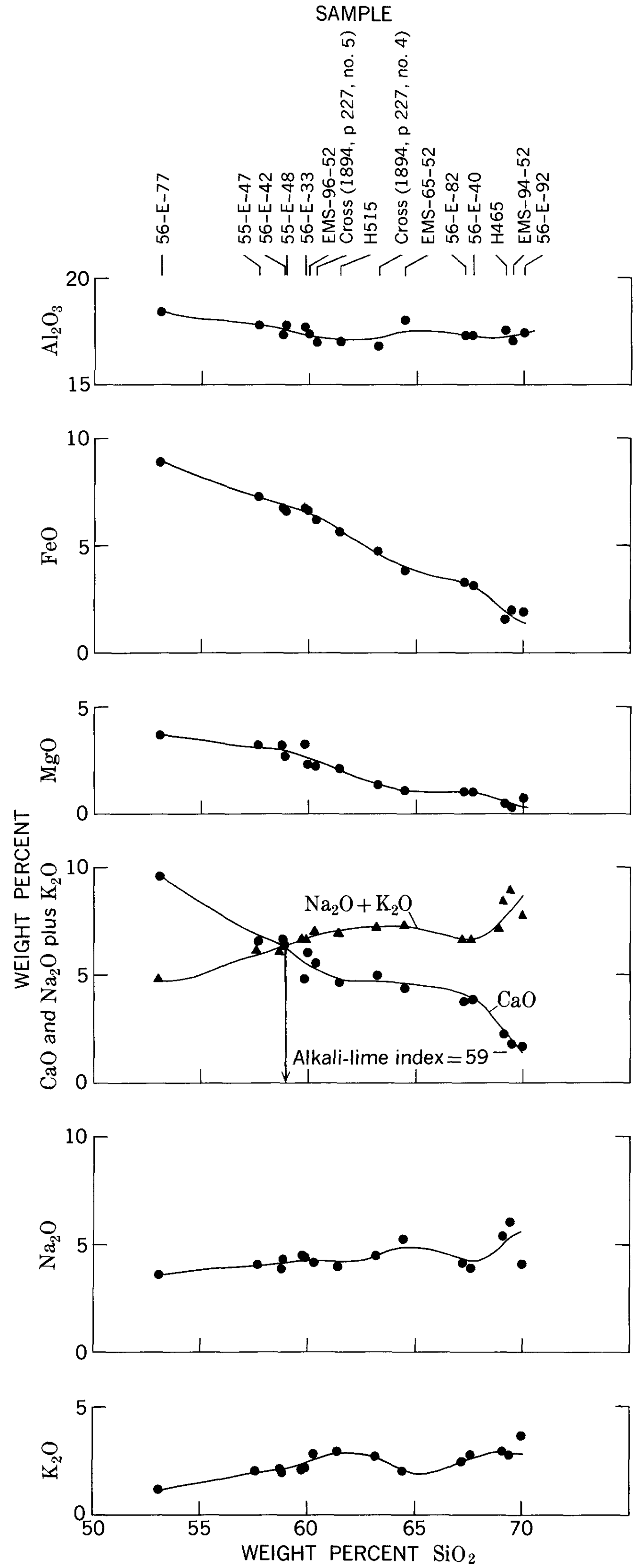


FIGURE 11.—Variation diagrams for igneous rocks of the Ute Mountains. All analyses in weight percent recalculated (minus H_2O, SO_3, and CO_2) to 100 percent. Analyses are shown in table 3.

alkalic field. Significantly, the alkali-lime index of the Ute Mountains rocks is similar to that of other laccolithic groups in the Colorado Plateau. Indices for porphyritic rocks of the La Plata Mountains from analyses published by Cross and Purington (1899, p. 6–7), for rocks of the Carrizo Mountains from analyses made available by E. M. Shoemaker and J. D. Strobell, and for the Abajo Mountains from analyses furnished by I. J. Witkind and E. M. Shoemaker, were computed as follows:

La Plata Mountains	≈57
Carrizo Mountains	≈58
Abajo Mountains	60.5

The alkali-lime indices are not listed for the rocks in the Henry and La Sal Mountains laccolithic groups because they are too uncertain. Many of these rocks are high in alkalies and low in silica (Hunt and others, 1953, p. 154; Hunt, 1958, p. 324–333). Graphs of their oxides show a wide dispersion of points that do not define single curves for either lime or total alkalies. More than one igneous series may be represented in these laccolithic groups. Analyses of only the diorite porphyry and the monzonite porphyry in the Henry and La Sal Mountains suggest an alkali-lime index between 59 and 62.

Thornton and Tuttle (1956) suggested a diagram to illustrate trends from mafic to felsic rocks without regard to the processes contributing to the formation of the rocks. In this diagram, oxide weight percentages are plotted against the sum of normative quartz, albite, orthoclase, nepheline, leucite, and kaliophilite. This sum is called differentiation index because of the tendency for all magmas to change in composition toward the system quartz-nepheline-kaliophilite. In figure 12 the oxide weight percentages of rocks from the Ute Mountains are plotted against the sum of normative quartz, albite, and orthoclase, there being no normative nepheline, leucite, or kaliophilite. Figure 12 is subdivided according to the scheme of Sukheswala and Poldervaart (1958, p. 1489). Except for Fe_2O_3 and FeO, the scattering of points is very minor, and straight lines fit the points very well. The scattering of Fe_2O_3 and FeO is thought to be due to mutually compensating variations of the two individual iron oxides. SiO_2 shows a gradual increase throughout the series; Al_2O_3 is nearly constant throughout; TiO_2, MgO, and CaO show steady decreases. Na_2O and K_2O increase throughout the series. The microgabbro has a differentiation index of 40, and it plots in the field of late-stage basalt. The diorite falls in the field of intermediate differentiates; the granodiorite falls along the boundary between the intermediate differentiates and the felsic differentiates having indices ranging from about 63 to 75. The quartz monzonite falls in the field of felsic differentiates having indices between 82 and 87.

MINOR ELEMENTS

VARIATION IN THE IGNEOUS ROCK SERIES

The minor elements of the igneous rocks are shown in tables 4 and 5. All amounts, except for those of titanium and manganese, were determined by semiquantitative spectrographic analysis. In this procedure a weighed amount of the sample mixture is burned in a controlled d-c arc and the spectrum recorded on a photographic plate. Selected lines on the resulting plate are visually compared with those of standard spectra prepared in a manner similar to that for the unknowns. The approximate visual detection limits for the elements determined by this semiquantitative spectrographic method are shown in table 4A. The assigned group for semiquantitative results will include the quantitative value about 60 percent of the time (Myers, Havens, and Dunton, 1961). The chemical analyses for titanium and manganese were by methods described by Shapiro and Brannock (1956).

Frequency distribution of minor elements in each type of rock is shown by histograms in figure 13. Some of the histograms depart considerably from a normal distribution curve, as, for example, cobalt in the granodiorite. The spread in values is probably due partly to variation between samples and partly to the analytical method. Although the mean content of cobalt cannot be determined accurately from these values, the trend of cobalt values from about 17 ppm (parts per million) in the diorite to a trace in the quartz monzonite is significant.

In determining the geometric mean of an element for which one or more values were reported as zero (amount is below the visual detection limit), it was assumed that because the majority of the samples showed significant quantities, that element is present in the remaining samples, but in amounts slightly less than the sensitivity. For example, in the diorite, 4 samples were analyzed as having less than sensitivity values for nickel and 19 samples contained determinable amounts. In determining a mean value for the 23 analyses, the 4 samples were assumed to contain 0.00015 percent nickel (one-half the visual detection limit of 0.0003 percent for nickel). Values reported as trace were considered to be threshold amounts when computing the mean for an element.

In comparing the amounts of trace elements in the igneous rocks of the Ute Mountains to averages in other parts of the world (table 4), it is apparent that the

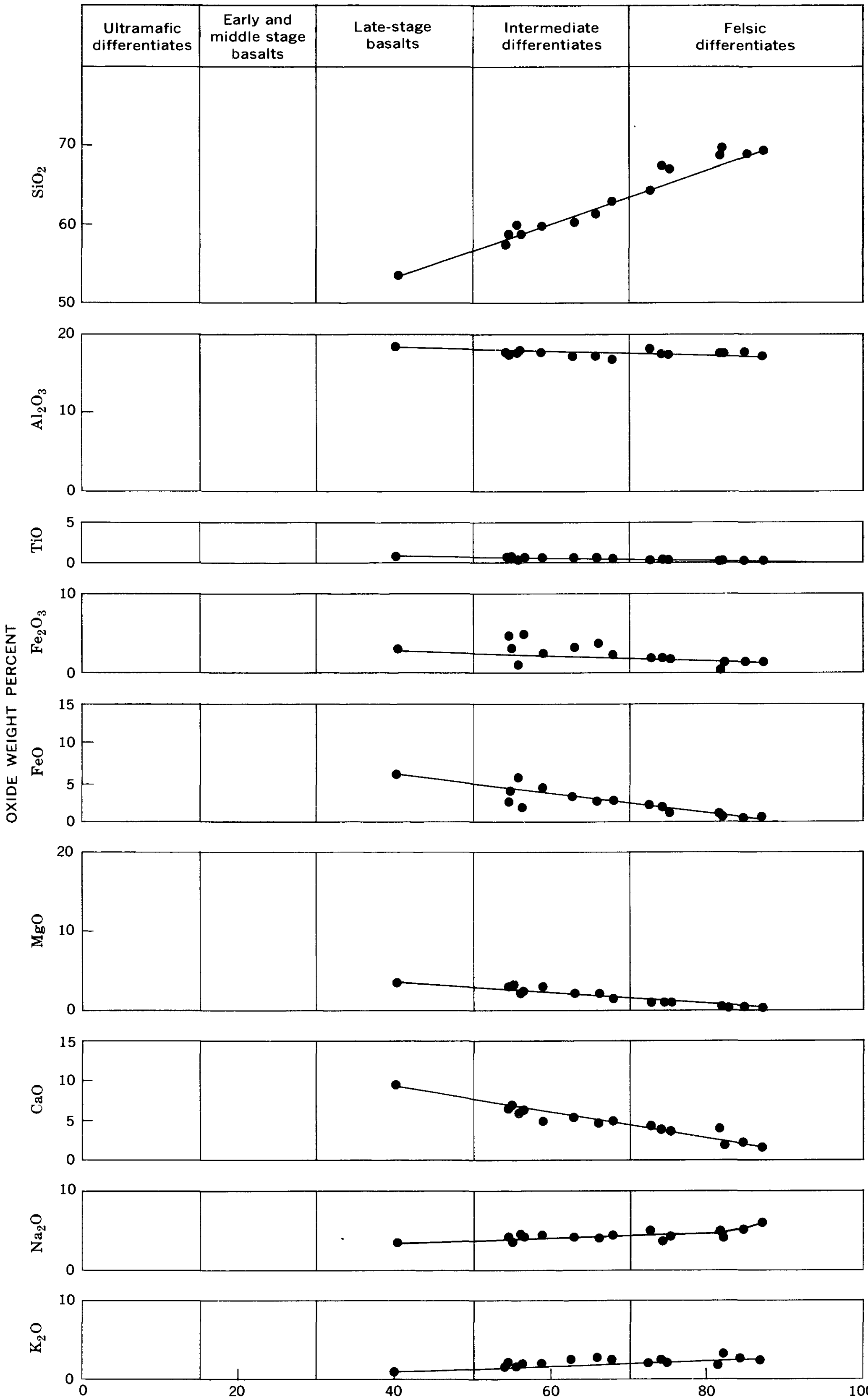


Figure 12.—Oxide weight percentages of rocks from the Ute Mountains plotted against the sum of normative quartz, albite, and orthoclase (the differentiation index). (After Thornton and Tuttle, 1956, and Sukheswala and Poldervaart, 1958.)

TABLE 4.—*Semiquantitative spectrographic and chemical analyses, in parts per million, of igneous rocks from the Ute Mountains*

[All values, except italic, are geometric means (antilogs of mean logs) determined from semiquantitative spectrographic analyses (table 5; *See* Miesch and Riley, 1961). Italic values were determined from chemical analyses (values for microgabbro is based on a single chemical analysis; for diorite porphyry on 5 analyses; for granodiorite on 6 analyses; for quartz monzonite on 4 analyses). Semiquantitative spectrographic determinations made by the rapid visual-comparison method. Comparisons of similar data with those obtained by quantitative methods show that the assigned semiquantitative-class interval includes the quantitative value in about 60 percent of the determinations. Tr., near threshold amount of element. Analysts: Spectrographic, N. M. Conklin, R. G. Havens, J. C. Hamilton, P. J. Dunton; chemical, P. L. D. Elmore, S. D. Botts, M. D. Mack, K. E. White]

Element	Microgabbro (3 analyses)	Diorite porphyry (23 analyses)	Granodiorite porphyry (9 analyses)	Quartz monzonite porphyry (6 analyses)	Lamprophyre (3 analyses)	Average abundance (world-wide distribution)	
						Gabbro	Diorite
Barium	410	660	740	880	530	60	[1] 230
Beryllium	(2)	(2)	Tr.	Tr.	(2)	[3] 2	[4] 3
Boron	(2)	(2)	(2)	Tr.	(2)	[5] 3	
Cobalt	68	17	11	Tr.	25	79	[6] 32
Chromium	88	6	5	3	50	340	[6] 68
Copper	150	30	16	10	115	149	[7] 38
Gallium	30	18	17	19	18	12.8	[8] 14.5
Lanthanum	(2)	Tr.	≈30	Tr.	(2)	9	[6] 26
Manganese	*1,240*	*1,080*	*850*	*460*	*1,240*	1,160	[9] 696
Molybdenum	<10	Tr.	(2)	(2)	(2)	[10] 3	[7] 2.5
Nickel	40	5	4	Tr.	15	158	[6] 40
Niobium	(2)	(2)	Tr.	Tr.	(2)	19	[11] 3.6
Lead	Tr.	Tr.	12	15	Tr.	5	[12] 30
Scandium	50	17	13	≈5	32	20	[3] 4.6
Strontium	680	1,060	1,040	880	680	170	[13] 260
Titanium	*5,100*	*4,200*	*2,700*	*1,100*	*7,200*	[14] 4,400	
Vanadium	315	150	74	25	245	[14] 150	
Yttrium	41	23	32	≈13	30	[11] 7.9	
Ytterbium	5	3	3	≈1.5	4	[15] 1	
Zirconium	70	115	125	100	70	140	[16] 280

[1] Engelhardt (1936).
[2] Indicates the amount is less than the sensitivity.
[3] Goldschmidt (1954).
[4] Sandell (1952).
[5] Goldschmidt and Peters (1932c).
[6] Goldschmidt (1937a).
[7] Sandell and Goldich (1943).
[8] Sandell (1947).
[9] Otto (1936).
[10] Hevesy and Hobbie (1933).
[11] Rankama and Sahama (1950).
[12] Hevesy, Hobbie, and Holmes (1931).
[13] Noll (1934).
[14] Goldschmidt (1937b) (average for igneous rocks).
[15] Tongeren (1938) (average for igneous rocks).
[16] Hevesy and Würstlin (1934).

Ute Mountains rocks are relatively high in barium, strontium, scandium, and low in chromium, nickel, and zirconium.

Barium exhibits a marked increase from about 400 ppm in the microgabbro to more than 800 ppm in the quartz monzonite porphyry. Most of the barium is probably contained in the potassium feldspar and biotite. Strontium is most abundant in the diorite and granodiorite, where it is probably present in both the plagioclase and potassium feldspars. Beryllium was detected only in the granodiorite and quartz monzonite, and boron only in the quartz monzonite.

The amounts of cobalt, chromium, copper, manganese, nickel, scandium, titanium, and vanadium are relatively high in the microgabbro and low in the quartz monzonite porphyry. These elements are nearly all confined to the mafic minerals. In figure 14, five elements (vanadium, copper, cobalt, chromium, and nickel) are plotted against total silica and pyribole. In general, the five elements decrease gradually in amount from microgabbro to quartz monzonite. However, two samples of diorite porphyry, 56–E–42 and 56–E–33, are unusually high in mafic minerals for diorite in the Ute Mountains. Sample 56–E–42 contains approximately 9 percent pyroxene and 7 percent hornblende, and although sample 56–E–33 contains no pyroxene, it has 17 percent hornblende.

Gallium is markedly more abundant in the microgabbro than in the other rocks. Lanthanum was found in appreciable quantities only in the granodiorite porphyry. Lanthanide elements are admitted by capture into the crystal lattices of compounds of quadrivalent elements of similar size, such as zirconium (Goldschmidt, 1954, p. 315). The lanthanum in the granodiorite may be related to the greater abundance of zircon in these rocks. Yttrium and ytterbium do not follow the variation in lanthanum, and they show a slight decline as silica increases in the rock series. Traces of molybdenum were detected only in the microgabbro and in the diorite porphyry. Niobium in amounts near the visual detection limit was observed only in the granodiorite and quartz monzonite. Lead gradually increases from barely detectable amounts in the microgabbro and diorite to approximately 15 ppm in the quartz monzonite.

VARIATION OF MINOR ELEMENTS WITH ROCK ALTERATION

VARIATIONS IN IGNEOUS ROCKS

As previously mentioned in (p. 35) the intrusive rocks of the Ute Mountains are partly or wholly altered. Most of the alteration is due to the action of deuteric solutions; however, the Mable Mountain bysmalith and associated dike were altered by sulfide-bearing solutions which were introduced after the intrusive masses had completely solidified.

Paired samples or suites of samples of altered and unaltered rocks were taken from several intrusive bodies. These samples were analyzed spectrograph-

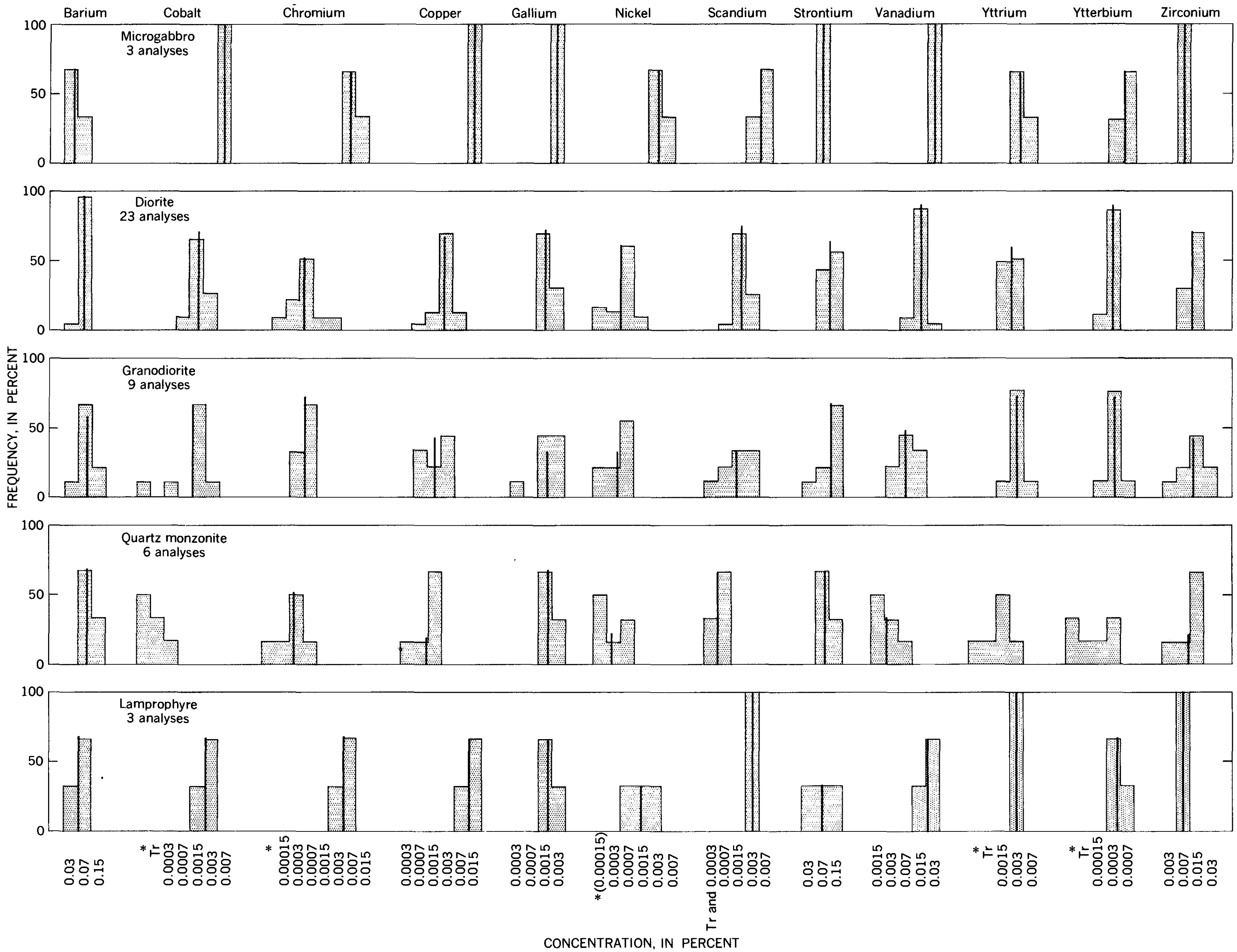


FIGURE 13.—Frequency distribution histograms of semiquantitative spectrographic analyses of minor elements common to the igneous rocks of the Ute Mountains. The vertical line in each group is the approximate plot of the geometric mean. Asterisk (*) indicates the amount is less than the sensitivity; Tr, near threshold amount of element. The nickel histogram for quartz monzonite includes one reporting of trace graphed at 0.0003.

TABLE 5.—*Semiquantitative spectrographic analyses*

Percent	*Code*
>10	XX
5 -10	X+
2 - 5	X
1 - 2	X−
.5 - 1	.X+
.2 - .5	.X
.1 - .2	.X−
.05- .1	.0X+

[Sample numbers with prefix H were collected by F. N. Houser; prefix EMS, E. M. Shoemaker. Analysts: 1, N. M. Conklin; 2, R. G. Havens; 3, J. C. Hamilton. ------- looked for but not detected. Approximate visual detection limits for the elements determined by the semiquantitative spectrographic methods at the Denver laboratory,

Rock type	Sample No.		Elements													
	Field	Laboratory	Analyst	Si (0.002)	Al (0.001)	Fe (0.0008)	Mg (0.0005)	Ca (0.005)	Na (0.05) ([1] 0.0005)	K (0.7) ([1] 0.002)	Ti (0.0002)	P (0.2)	Mn (0.0002)	B (0.002)	Ba (0.0002)	Be (0.0001)
Microgabbro porphyry	56-E-76	244798	1	XX	XX	XX	X	XX	X	X	0.X	------	0.X−	------	0.0X	------
	56-E-77	244799	1	XX	XX	XX	X	XX	X	X	.X	------	.X	------	.0X	------
Diorite porphyry	56-E-94	244713	1	XX	XX	X+	X+	X+	X	X	.X	------	.X−	------	.0X+	Tr.
	55-E-44A	238259	2	XX	XX	X+	X−	X	X	X	.X	------	.0X+	------	.0X+	------
	55-E-47B	238260	2	XX	XX	X	X	X+	X	X	.X	------	.X−	------	.0X+	------
	55-E-48B	238261	2	XX	XX	X	X−	X	X	X	.X	------	.X−	------	.0X+	------
	55-E-49	238262	2	XX	XX	X	X−	X	X	X	.X	------	.0X+	------	.0X+	------
	55-E-50A	238263	2	XX	XX	X	X−	X	X+	X	.X	------	.0X+	------	.0X+	------
	56-E-33	244757	1	XX	XX	X+	X	X+	X+	X	.X	------	.X−	------	.0X+	Tr.
	56-E-37	244760	1	XX	XX	X+	X	X+	X	X	.X	------	.X−	------	.0X+	Tr.
Altered diorite porphyry (mate to 56-E-37)	56-E-38	244761	1	XX	XX	X+	X	X+	X+	X	.X	------	.X−	------	.0X+	Tr.
Diorite porphyry	56-E-42	244764	1	XX	XX	X	X	X	X	X	.X	------	.X−	------	.0X+	------
	56-E-78	244800	1	XX	X+	X	X	X	X	X	.X−	------	.X−	------	.0X	------
	56-E-175	253492	3	XX	XX	X	X	X	X	X	.X	------	.X−	------	.0X+	------
	56-E-189-4	251988	1	XX	XX	X+	X−	X+	X	X	.X+	------	.X−	------	.0X+	------
	H 387-2	251993	1	XX	XX	X	X−	X+	X	X	.X	------	.X−	------	.0X+	------
	H 398-1	251994	1	XX	XX	X	X−	X+	X	X	.X	------	.X−	------	.0X+	------
	H 408-1	251995	1	XX	XX	X	X−	X	X	X	.X	------	.X−	------	.0X+	------
	H 411-2	251996	1	XX	XX	X	X−	X	X+	X	.X	------	.X+	------	.0X+	------
	H 414-1	251997	1	XX	XX	X	X−	X	X	X	.X+	------	.X−	------	.0X+	------
	H 517-1	252026	1	XX	XX	X	X−	X	X	X	.X+	------	.X−	------	.0X+	------
	H 533-2	252031	1	XX	XX	X	X−	X+	X	X	.X+	------	.X−	------	.0X+	------
	H 534-2	252032	1	XX	XX	X+	X−	X+	X	X	.X+	------	.X−	------	.0X+	------
Altered diorite porphyry (mate to H 387-2)	H 387-1	251992	1	XX	XX	X	X−	X+	X+	X	.X+	------	X−	------	.0X+	Tr.
Diorite porphyry (mate to H 387-1)	H 387-2	251993	1	XX	XX	X	X−	X+	X	X	.X	------	.X−	------	.0X+	Tr.
Diorite porphyry	EMS-96-52	D-81653	----	XX	XX	X	X−	X	X	X−	.X−	------	.X−	------	.0X	------
Granodiorite porphyry	56-E-51A	244772	1	XX	XX	X	X−	X	X	X	.X	------	.X+	------	.0X+	Tr.
	56-E-82	244804	1	XX	XX	X	X−	X	X	X	.X−	------	.X−	------	.0X+	0.000X−
	56-E-88	244708	1	XX	XX	X+	X	X+	X	X	.X	------	.X−	------	.0X+	.000X−
	H 270-1	244834	1	XX	XX	X	X−	X	X+	X	.X	------	.0X+	------	.0X+	Tr.
	H 373-1	251991	1	XX	XX	X	X−	X	X	X	.X	------	.0X+	------	.X−	------
	H 515-2	252024	1	XX	XX	X	X−	X+	X	X	.X	------	.0X+	------	.0X+	------
	H 516-2	252025	1	XX	XX	X+	X−	X+	X	X	.X+	------	.X−	------	.0X+	------
	56-E-40	244762	1	XX	XX	X	X−	X	X	X	.X−	------	.X−	------	.X−	.000X−
	EMS-65-52	D-77081	4	XX	X	X	X	X	X	.X	.X	------	.0X	------	.0X	------
Quartz monzonite porphyry	56-E-13	244743	1	XX	XX	X−	.X+	X	X+	X	.X−	------	.0X+	.00X	.X−	.000X−
	56-E-92	244812	1	XX	XX	X	.X+	X	X	X	.X−	------	.0X+	------	.0X+	.000X−
	H 465-1	252004	1	XX	XX	X	.X	X−	X+	X	.X−	------	.0X+	------	.0X+	Tr.
	H 526	252030	1	XX	XX	X	.X	X−	X	X+	.X−	------	.0X+	------	.X−	------
	EMS-94-52	D-81651	2	XX	XX	X−	.X	X−	X	X−	.0X+	------	.0X+	------	.0X+	------
	EMS-95-52	D-81652	2	XX	XX	X−	.X	X−	X	X−	.0X+	------	.0X+	------	.0X+	------
Lamporphyre	55-E-46A	253490	3	XX	XX	X+	X+	X+	X	X	.X+	------	.X−	------	.0X	------
	55-E-40C	238258	2	XX	XX	X	X	X	X+	X	.X	------	.0X+	------	.0X+	------
	55-E-51	238264	2	XX	XX	X+	X	X	X	X	.X	------	.X−	------	.0X+	------

[1] A different exposure is required for the lower detectabilities shown.

ically, and the results of the analyses are shown in table 6.

Apparently, there are few consistent variations. For example, the data from suite 7, taken from the Three Forks intrusive mass, a laccolith with an intensely altered center, show that vanadium was removed during alteration of diorite porphyry, but samples from other intrusive bodies show virtually no variation in vanadium.

Cobalt decreases in the altered rock of three suites, 6, 7, and 9, and increases in altered rock in suite 8. Suite 9 is sheared rock from Ute Creek dike which extends from the Mable Mountain bysmalith and contains copper deposits. Nickel and chromium decrease slightly in the altered rocks of several of the suites. Although these variations are small and generally within a single order of magnitude, they appear to be significant because sedimentary rocks adjacent to the igneous intrusive rocks have corresponding increases in these elements. Variations in equivalent uranium are slight as determined by radiometric analyses (a maximum of 2 ppm for one suite). Chemical determinations of uranium for one suite show virtually no variation.

of igneous rocks from the Ute Mountains, Colo.

Percent	*Code*
0.02 –0.05	0.0X
.01 – .02	.0X−
.005 – .01	.00X+
.002 – .005	.00X
.001 – .002	.00X−
.0005– .0001	.000X+
.0002– .0005	.000X
.0001– .0002	.000X−

U.S. Geological Survey (revised August 1956,) are shown in parentheses. Some combinations of elements affect the detectabilities. Approximate values are given. In unusually favorable materials, concentrations somewhat lower than the values given may be detected. In unfavorable materials, the given detectabilities may not be obtained for some of the elements]

Elements—Continued

Co (0.0005)	Cr (0.0001)	Cu (0.0001)	Ga (0.0002)	La (0.002)	Mo (0.0005)	Nb (0.001)	Ni (0.0003)	Pb (0.001)	Sc (0.0005)	Sr (0.0002)	V (0.001)	Y (0.001)	Yb (0.0005)	Zr (0.001)
0.00X+	0.00X+	0.0X−	0.00X	Tr.	<0.001	----	0.00X	Tr.	0.00X	0.0X+	0.0X	0.00X+	0.000X+	0.00X+
.00X+	.00X+	.0X−	.00X	----	<.001	----	.00X	----	.00X+	.0X+	.0X	.00X	.000X+	.00X+
.00X+	.0X−	.0X−	.00X	----	<.001	----	.00X+	Tr.	.00X+	.0X+	.0X	.00X	.000X	.00X+
.00X−	.000X+	.00X	.00X−	----	----	----	.000X+	Tr.	.00X	.0X+	.0X−	.00X	.000X	.0X−
.00X−	.000X+	.00X	.00X−	----	----	----	.000X+	Tr.	.00X	.X−	.0X−	.00X−	.000X	.00X+
.00X−	.000X+	.00X	.00X−	----	----	----	.000X+	Tr.	.00X−	.0X+	.0X−	.00X−	.000X−	.00X+
.00X+	.000X	.00X	.00X−	----	----	----	.000X+	0.00X−	.00X−	.0X+	.0X−	.00X−	.000X−	.00X+
.00X−	.000X+	.00X	.00X−	----	----	----	.000X+	.00X−	.00X−	.X−	.0X−	.00X	.000X	.0X−
.00X	.00X	.00X+	.00X	0.00X	----	----	.00X−	Tr.	.00X	.0X+	.0X	.00X	.000X	.0X−
.00X	.000X+	.00X	.00X	Tr.	----	----	.000X+	Tr.	.00X	.X−	.0X−	.00X	.000X	.0X−
.00X	.000X+	.00X	.00X	.00X	----	----	----	.00X−	.00X−	.X−	.0X−	.00X	.000X	.0X−
.00X	.00X−	.00X+	.00X	----	----	----	.000X+	.00X−	.00X−	.0X+	.0X−	.00X−	.000X	.0X−
.00X	.000X+	.00X+	.00X	----	----	----	.000X+	----	.00X−	.0X+	.0X−	.00X−	.000X	.00X+
.00X−	.000X+	.00X	.00X	.00X	----	----	----	----	.00X−	.0X+	.0X−	.00X	.000X	.00X+
.00X	.00X−	.00X	.00X−	----	----	----	.00X−	Tr.	.00X	.X−	.0X−	.00X	.000X	.0X−
.00X−	.000X+	.00X	.00X−	.00X	----	----	.000X+	.00X−	.00X−	.X−	.0X−	.00X	.000X	.0X−
.00X−	.000X	.00X	.00X−	.00X	----	----	.000X+	Tr.	.00X−	.X−	.0X−	.00X	.000X	.0X−
.00X−	.000X−	.00X−	.00X−	----	----	----	----	.00X−	.00X−	.0X+	.00X+	.00X−	.000X	.0X−
.000X+	.000X−	.000X+	.00X−	.00X	----	----	----	Tr.	.00X−	.X−	.0X−	.00X	.000X	.0X−
.00X−	.000X	.00X	.00X−	.00X	----	----	.000X	Tr.	.00X−	.X−	.0X−	.00X−	.000X	.0X−
.00X−	.000X	.00X−	.00X−	.00X	Tr.	----	.000X	.00X−	.00X−	.X−	.0X−	.00X	.000X	.0X−
.00X−	.000X+	.00X	.00X−	----	----	----	.000X+	Tr.	.00X−	.0X+	.0X−	.00X−	.000X	.0X−
.00X−	.00X	.00X	.00X−	----	----	----	.000X+	Tr.	.00X−	.X−	.0X−	.00X−	.000X	.00X+
.00X−	.000X+	.00X	.00X	.00X	----	----	.000X+	.00X−	.00X	.X−	.00X	.000X	.0X−	.0X−
.00X−	.000X+	.00X	.00X	.00X	----	----	.000X+	.00X−	.00X+	.X−	.0X−	.00X	.000X	.0X−
.000X+	.000X+	.00X	.00X−	----	----	----	.000X+	----	.000X+	.0X+	.00X+	.000X−	.000X−	.00X+
.00X−	.000X+	.000X+	.00X	.00X	----	----	Tr.	.00X−	.00X	.X−	.00X+	.00X	.000X	.0X
.00X−	.000X+	.00X	.00X−	.00X	----	0.00X−	.000X+	.00X−	.000X+	.0X+	.00X+	.00X	.000X	.0X−
.00X	.000X+	.00X	.00X	.00X+	----	----	.000X+	Tr.	.00X	.0X−	.0X−	.00X+	.000X+	.00X+
.00X−	.000X+	.000X+	.00X	----	----	.00X−	.000X+	.00X	.00X−	.X−	.00X+	.00X−	.000X−	.0X−
----	.000X	.000X+	.00X−	.00X	----	----	----	.00X−	.000X+	.X−	.00X	.00X	.000X	.0X−
.00X−	.000X+	.00X	.00X−	.00X	----	----	.000X+	.00X−	.00X−	.X−	.0X−	.00X	.000X	.00X+
.00X−	.000X	.00X−	.00X−	.00X	----	----	.000X	----	.00X−	.X−	.0X−	.00X	.000X	.0X−
.00X−	.000X+	.00X−	.00X	.00X+	----	.00X−	.000X+	.00X−	.00X	.0X+	.00X+	.00X	.000X	.0X
.000X	.000X	.00X	.000X	----	----	----	.000X	----	.000X	.0X	.00X	.00X	.000X	.00X
Tr.	.000X+	.000X+	.00X	----	----	.00X−	Tr.	.00X	.000X+	.0X+	.00X+	.00X−	.000X−	.0X−
Tr.	.000X−	.00X−	.00X	.00X	----	.00X−	----	.00X−	.000X+	.0X+	.00X	.00X	.000X	.0X−
----	.000X	.000X	.00X−	----	----	.00X−	----	.00X−	.000X+	.X−	.00X	Tr.	Tr.	.0X−
----	----	.00X−	.00X−	----	----	----	----	.00X−	.000X+	.X−	.00X−	.00X−	.000X	.0X−
.000X	.000X	.00X−	.00X−	----	----	----	.000X+	----	----	.0X+	.00X−	.00X−	----	.00X+
----	.000X	.00X−	.00X−	----	----	----	.000X+	----	----	.0X+	.00X−	----	----	.00X
.00X	.00X+	.0X−	.00X	----	----	----	.00X	----	.00X	.X−	.0X	.00X	.000X+	.00X+
.00X−	.00X	.00X+	.00X−	----	----	----	.000X+	.0015	.00X	.0X	.0X−	.00X	.000X	.00X+
.00X	.00X+	.0X−	.00X−	----	----	----	.00X−	----	.00X	.0X+	.0X	.00X	.000X	.00X+

VARIATIONS IN SEDIMENTARY ROCKS ADJACENT TO IGNEOUS INTRUSIVES

The Junction Creek Sandstone exhibits color changes wherever exposed in the vicinity of intrusive rocks in the Ute Mountains area. Away from intrusive rock the sandstone is predominantly orange or red. Adjacent to intrusive rock, the color is light brown or yellow brown, probably because of the introduction of iron oxide.

Spectrographic analyses of paired samples of red unaltered sandstone and yellow-brown altered sandstone (table 6) indicate that cobalt, chromium, gallium, nickel, strontium, vanadium, yttrium, and ytterbium are more abundant in the altered than in the fresh rock. Samples of Dakota Sandstone (table 6, suite 10) yielded generally similar results. The altered Dakota Sandstone was taken about 20 yards from a contact with granodiorite porphyry, and the unaltered specimen was collected from the same sandstone bed about a mile from the nearest exposure of igneous rock. The altered Dakota Sandstone contains slightly greater amounts of chromium, copper, gallium, nickel, and ytterbium than the unaltered Dakota.

TABLE 6.—*Semiquantitative spectrographic analyses and radiometric analyses of*

[For code see table 5. Values in italic for altered rock differ from values for corresponding unaltered rock. Sample numbers with prefix EMS were collected by E. M. Shoemaker.

Pair or suite	Sample	Laboratory No.	Rock type	Spectrographic analyses: Analysts	Minor elements: Ba	Co	Cr	Cu	Ga	Mo	Ni	Pb	Sc
													Igneous
			Deuteric alteration										
1	55-E-47B	238260	Diorite porphyry	1	0.0X+	0.00X–	0.000X+	0.00X	0.00X–	---------	0.000X+	Tr.	0.00X
	55-E-48B	238261	Altered diorite porphyry	1	.0X+	.00X–	.000X+	.00X	.00X–	---------	.000X+	Tr.	*.00X–*
2	56-E-37	244760	Diorite porphyry	2	.0X+	.00X	.000X+	.00X	.00X	---------	.000X+	Tr.	.00X
	56-E-38	244761	Altered diorite porphyry	2	.0X+	.00X	.000X+	.00X	.00X	---------	---------	0.00X–	*.00X–*
3	56-E-77	244799	Microgabbro porphyry	2	.0X	.00X+	.00X+	.0X–	.00X	<0.001	.00X	---------	.00X+
	56-E-76	244798	Altered microgabbro porphyry.	2	.0X	.00X+	.00X+	.0X–	.00X	<.001	.00X	Tr.	*.00X*
4	H-387-2	251993	Diorite porphyry	2	.0X+	.00X–	.000X+	.00X	.00X–	---------	.000X+	.00X–	.00X–
	H-387-1	251992	Altered diorite porphyry	2	.0X+	.00X–	.000X+	.00X	.00X	---------	.000X+	.00X–	.00X
5	H-515-2	252024	Diorite porphyry	2	.0X+	.00X–	.000X+	.00X	.00X	---------	.000X+	.00X–	.00X–
	H-516-2	252025	Altered diorite porphyry	2	.0X+	.00X–	*.000X*	*.00X–*	.00X	---------	*.000X*	---------	.00X–
6	EMS-63-52	D77079	Granodiorite porphyry	3	.X	.000X+	.000X+	.00X	.000X	---------	.000X	---------	.000X
	EMS-65-52	D77081	Moderately altered granodiorite porphyry.	3	.0X	.000X+	.00X–	.00X	.000X	---------	.000X	---------	.000X
	EMS-66-52	D77082	Altered granodiorite porphyry.	3	.0X	*.000X*	.000X+	.00X	.000X	---------	.000X	---------	.000X
7	EMS-70-52	D77086	Intensely altered diorite porphyry.	3	.0X	*.000X+*	*Tr.*	.00X	.000X	---------	.000X	---------	.000X
	EMS-71-52	D77087	Altered diorite porphyry	3	.0X	.00X–	.000X	.00X	.000X	---------	.000X	.00X	.000X
	EMS-72-52	D77088	Diorite porphyry	3	.0X	.00X–	.000X	.00X	.000X	---------	.000X	.00X	.000X
8	EMS-73-52	D77089	Altered diorite porphyry	3	.0X	.00X–	.000X	.00X	.000X	---------	.000X	---------	.000X
	EMS-74-52	D77090	Diorite porphyry	3	.0X	.000X+	.000X	.00X	.000X	---------	.000X	---------	.000X
			Hydrothermal										
9	EMS-12-53	D88148	Altered diorite porphyry	4	.0X–	---------	*.000X+*	*.00X+*	.00X–	.00X	*.000X+*	---------	.000X+
	EMS-14-53	D88150	Diorite porphyry	4	.00X+	.00X–	.00X–	.0X+	.00X–	.00X–	.00X–	Tr.	.000X+
													Sedimentary
10	56-E-20	244747	Altered fossiliferous Dakota Sandstone.	2	*0.0X–*	---------	*0.00X–*	*0.00X–*	*Tr.*	---------	*0.000X+*	---------	---------
	56-E-224	253493	Unaltered fossiliferous Dakota Sandstone.	5	.00X	---------	.000X+	.000X+	---------	---------	---------	---------	---------
11	56-E-15	244745	Altered Junction Creek Sandstone.	2	.0X	*Tr.*	*.00X–*	.000X+	*0.000X–*	---------	*.000X+*	---------	Tr.
	56-E-16	244746	Unaltered Junction Creek Sandstone.	2	.0X	---------	.000X+	.000X+	Tr.	---------	Tr.	---------	---------
12 [2]	56-E-51C	244774	Baked Mancos Shale	2	*.0X+*	*0.00X–*	*.00X+*	.00X	*.00X*	---------	*.00X+*	Tr.	0.00X–
	H-368-1	251990	do	2	.0X	*.00X–*	*.00X+*	.00X	.00X–	---------	*.00X*	0.00X+	.00X
	---------	---------	Unaltered Mancos Shale (average of three samples).	----	.032	.000X+	.004	.00X+	.00X–	0.001	.00X–	.00X–	.00X–
13	56-E-25	244751	Baked sandy limestone of the Mancos Shale.	2	*.000X+*	---------	.000X	*.00X–*	---------	---------	Tr.	---------	---------
	55-E-70	253491	Sandy limestone of the Mancos Shale.	5	.0X	---------	.000X	.000X+	---------	---------	---------	---------	---------

[1] Chemical uranium determination.

The variations in minor metallic elements noted above for the Junction Creek and the Dakota Sandstones are very slight and the quantities involved are near the limits of detection for those metals. Both sandstones are rather poorly sorted and differences in grain size may exist between the individual samples of a pair, even though such differences are not apparent with the hand lens. Other workers have found that the amount of a minor element varries considerably with grain size within a single stratum (V. C. Kennedy, oral commun., 1957). This relation may explain the variation noted in both the Junction Creek and Dakota Sandstones, but it seems more likely that the variations are related to the Ute instrusive rocks, because the effects of alteration are similar in the two sandstone formations. The Mancos Shale, which shows little variation in grain size, supplies corroborative evidence. Two samples of baked shale contain more cobalt, chromium, nickel, strontium, yttrium, and ytterbium than the unaltered shale (table 6, suit 12). Suite 13, baked and unbaked sandy limestone from the Mancos Shale, shows little variation except a loss of barium and a slight gain in copper, yttrium, and ytterbium in the baked sample.

The authors conclude that the altered and baked sediments adjacent to the Ute intrusive rocks gained small amounts of cobalt, chromium, gallium, nickel, yttrium, ytterbium, and probably vanadium. These elements apparently were transported by solutions from adjacent intrusive bodies.

altered and unaltered igneous and sedimentary rocks from the Ute Mountains, Colo.

Analysts—spectrographic: 1, R. G. Havens; 2, N. M. Conklin; 3, P. J. Dunton; 4, G. W. Boyes, Jr.; 5, J. C. Hamilton; radiometric: 1, C. G. Angelo; 2, J. P. Schuch]

Spectrographic analyses—Continued														Radiometric analyses	
Minor elements—Continued					Major elements									Equivalent uranium (percent)	Analysts
Sr	V	Y	Yb	Zr	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn		
rocks															
0.X−	0.0X−	0.00X−	0.000X	0.00X+	XX	XX	X	X	X+	X	X	0.X	0.X−	<0.001	1
.0X+	.0X−	.00X−	.000X−	.00X+	XX	XX	X	X−	X	X	X	.X	.X−	< .001	1
.X−	.0X−	.00X	.000X	.0X−	XX	XX	X+	X	X+	X	X	.X	.X−	.001	1
.X−	.0X−	.00X	.000X	.0X−	XX	XX	X+	X	X+	X+	X	.X	.X−	< .001	1
.0X+	.0X	.00X	.000X+	.00X+	XX	XX	XX	X	XX	X	X	.X	.X	< .001	1
.0X+	.0X	.00X+	.000X+	.00X+	XX	XX	XX	X	XX	X	X	.X	.X−	< .001	1
.X−	.0X−	.00X	.000X	.0X−	XX	XX	X	X−	X+	X	X	.X	.X−	< .001	1
.X−	.0X−	.00X	.000X	.0X−	XX	XX	X	X−	X+	X+	X	.X+	.X−	< .001	1
.X−	.0X−	.00X	.000X	.00X+	XX	XX	X	X−	X+	X	X	.X	.0X+	< .001	1
.X−	.0X−	.00X	.000X	.0X−	XX	XX	X+	X−	X+	X	X	.X+	.X−	.003	1
.X	.00X	.00X	.000X	.00X	XX	X	X	X	X	X	X	.X	.0X	----------	–
.0X	.00X	.00X	.000X	.00X	XX	X	X	X	X	X	.X	.X	.0X	----------	–
.0X	.00X	.00X	.000X	.00X	XX	X	X	.X	X	X	.X	.X	.0X	----------	–
.0X	.00X	.00X	.000X	.00X	XX	X	X	X	X	X	X	.X	.X	----------	–
.0X	.00X	.00X	.000X	.00X	XX	X	X	X	X	X	.X	.X	.X	----------	–
.0X	.0X	.00X	.000X	.00X	XX	X	X	X	X	X	.X	.X	.X	----------	–
.0X	.00X	.00X	.000X	.00X	XX	X	X	X	X	X	X	.X	.X	----------	–
.0X	.00X	.00X	.000X	.00X	XX	X	X	X	X	X	.X	.X	.X	----------	–
.0X	.0X−	Tr.	----------	.0X−	XX	XX	X	.0X+	.0X+	.0X+	.X+	.X	.0X−	[1] .0003(U)	2
.0X	.00X+	.00X−	----------	.00X+	XX	XX	X+	X	X.−	X.−	X.−	.X	.X−	[1] .0004(U)	2
rocks															
0.0X−	0.00X−	0.00X−	0.000X−	0.00X+	XX	0.X−	0.X+	0.X	XX	0.X	--------	0.0X	0.X−	<0.001	1
.0X−	.00X−	.00X−	----------	.00X−	XX	.X+	.X+	.X−	XX	.X−	--------	.0X	.X−	----------	1
.00X+	.00X	.00X−	.000X−	.0X	XX	X	.X+	.X	X	X+	X	.X−	.0X	< .001	1
.000X+	.00X−	----------	Tr.	.0X−	XX	X−	.X	.X−	X	.0X+	X−	.0X+	.0X	< .001	1
.0X+	.0X	.00X+	.000X+	.0X−	XX	XX	X	X	XX	X	X	.X−	.X−	.002	1
.0X+	.0X−	.00X−	.000X	.0X−	XX	XX	X	X−	XX	X+	X+	.X+	.0X	.002	1
.032	.0X−	.00X−	----------	.0X−	XX	X+	X−	.X+	.X+	.X	X	.X	X+	----------	–
.0X+	.00X−	.00X−	.000X−	.00X−	X+	.0X	.X+	X−	XX	.0X+	--------	.0X−	.0X+	< .001	1
.X−	.00X	----------	----------	.00X+	X	.X	.X+	.X+	XX	.X+	--------	.0X	.0X	----------	–

[2] Data from W. L. Newman and E. M. Shoemaker (written commun., 1952; average of three samples).

ORIGIN OF THE IGNEOUS ROCKS AND HORNBLENDE INCLUSIONS

The igneous rocks of the Ute Mountains are a group of intergrading hypabyssal intrusive rocks that changed in composition from gabbro to quartz monzonite as intrusion proceeded. This progressive change with time of intrusion suggests a derivation from a common ancester magma by some process of differentiation. The chemical composition of the phenocrysts of the microgabbro is very similar to the calculated chemical composition of material that might have been subtracted from microgabbro to form quartz monzonite. In figure 15 the major oxides are plotted against silica for microgabbro and quartz monzonite; the silica content of the most mafic material that might be subtracted from the microgabbro to obtain quartz monzonite is determined by projecting the line connecting the points for K_2O to 0.5 percent, which is considered to be a realistic value for a calc-alkalic magma. Other values are based on the silica value thus found (points on vertical line at left in figure 15A); they are compared to the chemical composition of microgabbro phenocrysts in table 7.

Augite, hornblende, and labradorite are the earliest mineral components of the rocks; it seems reasonable that large quantities of these crystals were separated from the magma by settling or by being pressed from the liquid during movement of the magma, thus changing the composition of the rest of the magma. If this process took place, it occurred before the magma rose

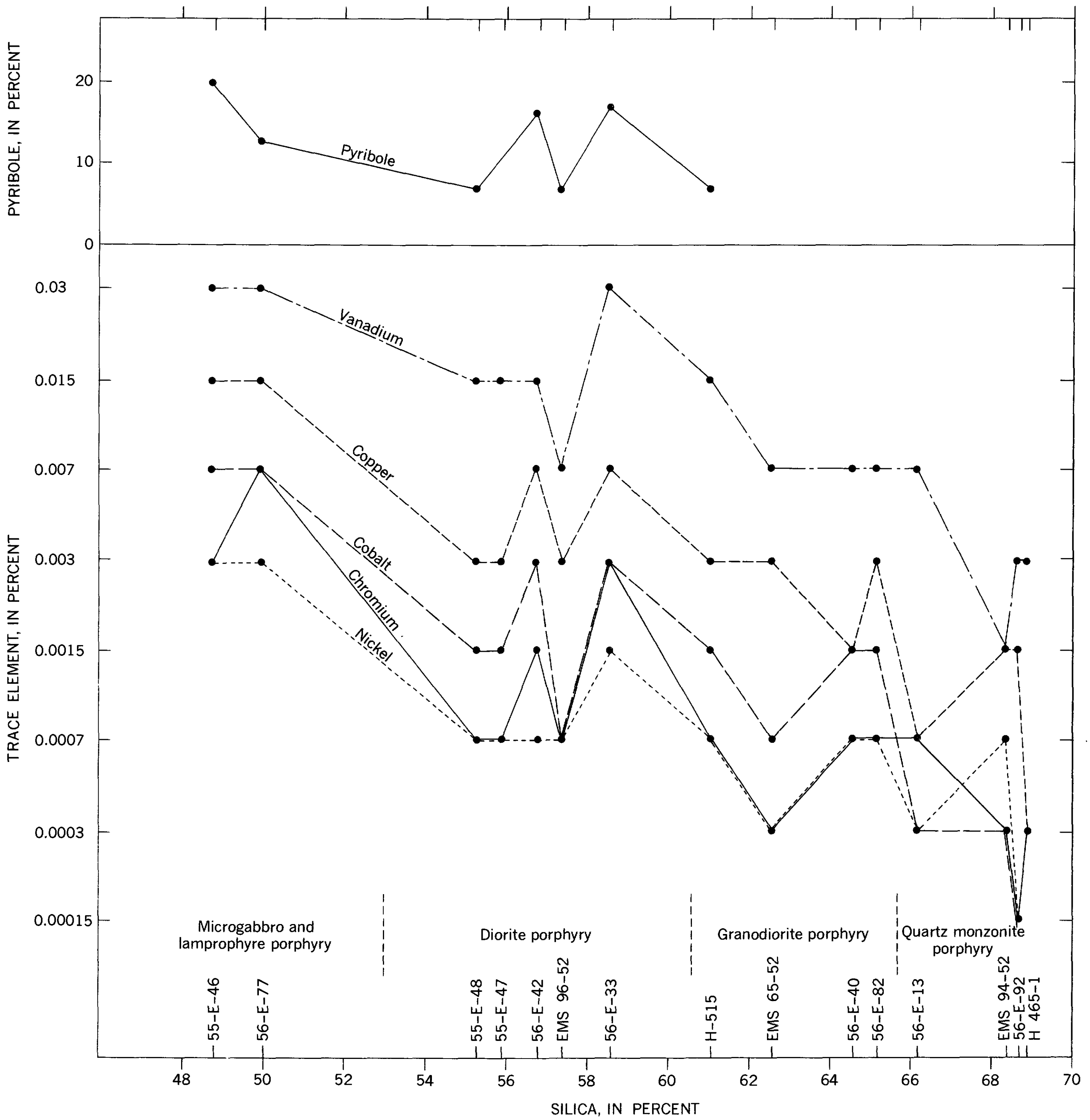


FIGURE 14.—Diagram showing variation of five trace elements with respect to increasing silica and total pyribole content. The pyribole includes pyroxene and amphibole. Pyribole in the granodiorite (excluding H–515) and quartz monzonite has been replaced by calcite, chlorite, and sericite. Sample numbers shown at bottom of chart. Percentage of trace element determined by semiquantitative spectrographic analysis.

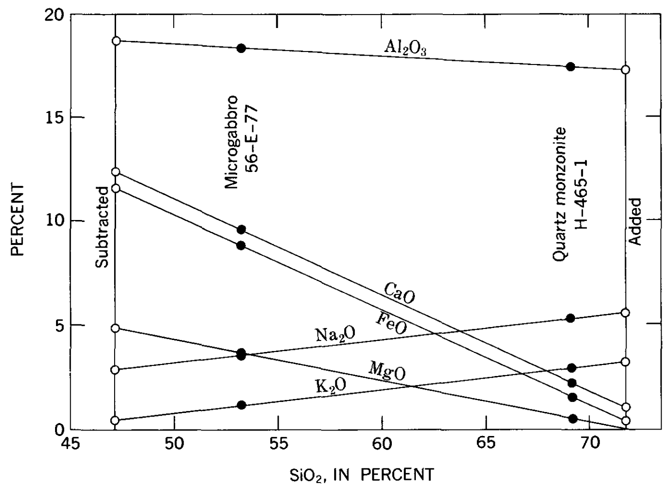


FIGURE 15.—Graphical solution of Harker diagram to determine possible materials added or subtracted to produce quartz monzonite from microgabbro.

TABLE 7.—*Comparison of the chemical composition of microgabbro phenocrysts with the chemical composition of material that might be subtracted from microgabbro to produce quartz monzonite*

[Mode of microgabbro phenocrysts was determined from thin section of field sample 56-E-77, in percent: Augite, 21.6; hornblende, 36.2; plagioclase, 40.5; magnetite, 1.7. The chemical composition of hornblende used in the calculation is an average of four chemical analyses of hornblende from the Ute Mountains. The chemical composition of augite is that given by Wahlstrom (1947, p. 238). Only plagioclase phenocrysts larger than about 0.3 mm were counted in the mode. These crystals are estimated to average about 60 percent anorthite in composition]

Constituent	Microgabbro phenocrysts	Subtracted material
SiO_2	46.9	47.2
Al_2O_3	17.5	18.7
FeO	10.7	11.6
CaO	13.5	12.5
MgO	7.3	5.0
Na_2O	2.5	2.9
K_2O	.3	.5

to the level of the intrusive bodies now visible, for these bodies are petrographically uniform throughout.

The hornblendic inclusions found widely in the igneous bodies of the Ute Mountains are also characteristic of other laccolithic mountain groups on the Colorado Plateau. The origin of these inclusions is probably closely related to the origin of the magma or magmas that gave rise to the laccolithic mountain groups.

In the Henry Mountains, hornblendic inclusions comprise 95 percent of the total of all inclusions (Hunt and others, 1953, p. 164). Hunt noted that the hornblende phenocrysts in the porphyries are not sharply distinguishable from aggregates of hornblende in the inclusions. He concluded:

> It seems necessary to infer that the hornblende inclusions were derived at great depths and have had a very different history than the obvious xenoliths. The inclusions may be altered fragments of diverse wall rock floated from great depths, or rock fragments from early differentiates in the magma reservoir, or fragments of marginal unfused layers of the substratum from which the magma was derived.

A. C. Waters and C. B. Hunt (in Hunt, 1958, p. 348–354) described hornblendic inclusions in the La Sal Mountains and suggested that the inclusions in the igneous rocks are either "* * * fragments of diverse wall rocks brought to equilibrium with a magma at great depths, or else they are the leftover unfused fragments of the substratum from which the magma itself was derived or perhaps both."

Waters and Hunt (Hunt, 1958, p. 348–355) pointed out that the evidence in the La Sal Mountains does not support the evolution of the igneous suite of rocks from diorite to syenite by crystallization differentiation of a primary basalt parent. They suggested that the igneous rocks in the La Sal Mountains were derived from a magma formed by the partial fusion of amphibolite or related metamorphic rocks. This anatectic theory satisfactorily explains: (a) the lack of basalt or its plutonic equivalents in the La Sal suite of rocks, (b) the lack of a progressive increase in silica in the later formed rocks, and (c) the similarity of the hornblende in the inclusions with the hornblende in the rock. The theory does not explain the absence of the mafic alkalic rocks which should result from fractionation of hornblende (Bowen, 1928, p. 269–273). However, Waters and Hunt (Hunt, 1958, p. 353) suggested that "filtration effects" took place that decreased the amount of mafic material carried upward by the rising magma. They did not attempt to extend their theory to explain the origin of all the laccolithic magmas of the Colorado Plateau, although the theory does have plateau-wide appeal because it could explain the hornblende inclusions characteristic of all the laccolithic mountain groups. Furthermore, if a hornblendic substratum as broad as the plateau is assumed to exist, the theory explains the similarity of the dioritic intrusive rocks in the laccolithic groups.

To provide further data bearing on the origin of the hornblendic inclusions and possibly on the magma of the Ute Mountains, two separates of hornblende phenocrysts from diorite porphyry and two of hornblende from inclusions were analyzed chemically, optically, and spectographically. (See tables 8, 9, 10, 11, 12.) The data derived from these analyses indicate that the two types of hornblende are very similar. The chemical similarity is especially apparent when plotted on a diagram designed by Hallimond (1943). In a study of hornblende from North America, Europe, Asia, and Africa, Hallimond found that a generalized relation exists between parent rock and the composition of the contained hornblende. He plotted the compositions of hornblende from nearly 200 localities on a triangular diagram in terms of two variables: (a) the number of Si atoms, and (b) the number of atoms alloted to the

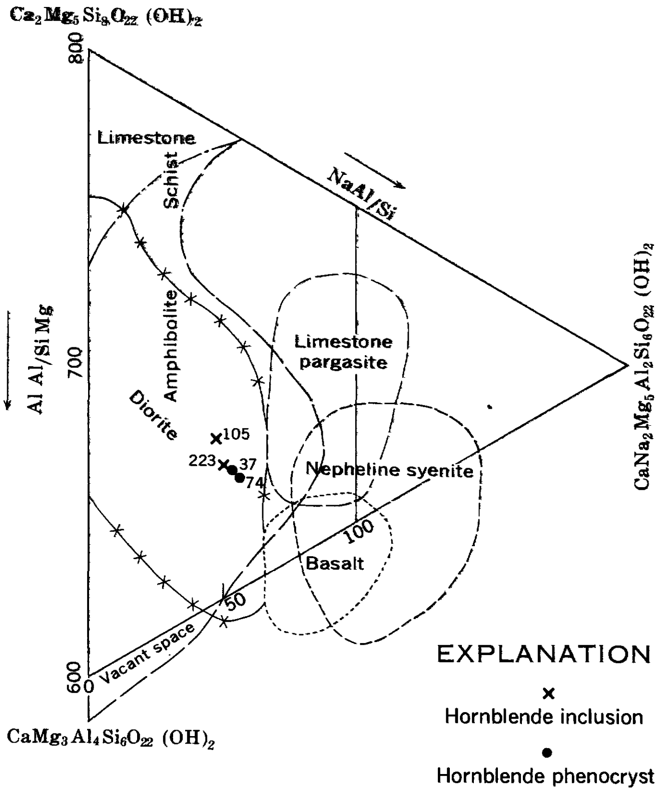


FIGURE 16.—Approximate limits of composition of amphibole derived from various rocks (Hallimond, 1943, p. 75) showing plot of four samples of hornblende from the Ute Mountains.

vacant space in the amphibole unit cell. Figure 16 is a reproduction of Hallimond's diagram with the composition points of two separates of hornblende phenocrysts and two separates of hornblende from inclusions of the Ute Mountains superimposed on it. All four fall within the diorite and amphibolite fields of Hallimond.

TABLE 8.—*Chemical analyses of hornblende from the Ute Mountains, Colo.*

[Analyses, in percent, by S. M. Berthold. Sample EMS-74-52 (collected by E. M. Shoemaker) is from the Three Fork laccolith; 56-E-37 is from a laccolith in the Yucca cluster (pl. 1) about 2,000 ft. southwest of Mushroom laccolith. Both samples are of hornblende phenocrysts from diorite porphyry. Samples 56-E-105 and 56-E-223 are from hornblendic inclusions in granodiorite porphyry of Black Mountain and of Sentinel Peak, respectively]

Field Sample	EMS-74-52	56-E-37	56-E-105	56-E-223
Laboratory No.	151063	151064	151065	151066
SiO_2	43.19	43.41	43.84	43.32
Al_2O_3	13.20	12.85	11.48	13.10
Fe_2O_3	3.32	3.20	4.80	4.89
FeO	10.88	10.82	11.60	10.42
MgO	11.14	11.82	11.34	10.90
CaO	11.38	11.42	11.46	10.92
Na_2O	2.06	2.04	1.70	1.98
K_2O	.77	.72	.81	.99
TiO_2	1.56	1.15	.84	1.06
P_2O_5	.10	.20	.05	.13
H_2O+	1.77	1.74	1.58	1.62
H_2O-	.53	.36	.16	.43
MnO	.28	.28	.27	.17
F	.37	.25	.14	.14
Total	100.55	100.26	100.07	100.07
−O=F	.16	.10	.06	.06
Total	100.39	100.16	100.01	100.01
Specific gravity	3.13	3.12	3.24	3.07
FeO:MgO	.55	.51	.57	.54

TABLE 9.—*Atomic ratios of elements in hornblende on basis 24 (O, OH, F)*

[The method used to recast the chemical analyses is that outlined by Groves (1951, p. 306-320) who used the general formula for monoclinic amphiboles: $(OH, F)_2 (Na, Ca, K)_{2-3} (Mg, Fe^{+2}, Fe^{+3}, Ti, Mn, Al)_5 [(Si, Al)_8 O_{22}]$]

Element	Ratio in field sample—			
	EMS-74-52	56-E-37	56-E-105	56-E-223
Si	6.36	6.40	6.52	6.42
Al_s[1]	1.64	1.59	1.48	1.58
Al_y	.66	.64	.53	.71
Ti	.17	.13	.09	.12
Fe^{+3}	.34	.36	.54	.55
Fe^{+2}	1.34	1.34	1.44	1.29
Mg	2.45	2.60	2.51	2.41
Mn	.04	.03	.03	.02
Na	.59	.58	.49	.57
Ca	1.80	1.81	1.83	1.73
K	.15	.14	.15	.19
OH	1.74	1.71	1.57	1.60
F	.17	.12	.07	.07
Y group [2]	5.02	5.09	5.15	5.10
$Mg+Al_y$: Y	.62	.64	.59	.61
$Mg+Al_y$: $Fe^{+3}+Fe^{+2}$	1.85	1.91	1.02	1.70
Fe^{+3}: Fe^{+2}	.25	.27	.38	.43
Na+Ca+K	2.54	2.53	2.47	2.49

[1] Al_s, aluminum used to make up the number of metal atoms in the chain to eight; Al_y, aluminum remaining which is assumed to replace Mg in the Y group.
[2] Y group includes Ti, Fe^{+3}, Fe^{+2}, Mg, and Mn.

TABLE 10.—*Optical properties of hornblende from the Ute Mountains*

[Determinations of indices of refraction by Marie Lindberg who found a considerable range in the indices of individual grains, especially for samples EMS-74-52 and 56-E-37. This lack of homogeneity may be due to zoning, a characteristic feature of hornblende from the Ute Mountains. All other optical determinations were made by E. B. Ekren. The extinction angles were measured on a four-axis universal stage using the method described by Turner (1942). Optic angles were measured directly on the universal stage. The accuracy of these measurement is believed to about ±1°. Abbreviations used in color descriptions: gn, green; gy, gray; lt, light; med, medium; p, pale; y, yellow; o, olive]

Optical property	Field sample			
	EMS-74-52	56-E-37	56-E-105	56-E-223
α	Min, 1.660; avg, 1.664.	Min, 1.65.	Min, 1.659.	Min, 1.653.
β	Min, 1.668; avg, 1.675–1.685.	Max, 1.67–1.69; avg, 1.673–1.678.	Range, 1.676–1.680; avg in low range.	Range, 1.665–1.675.
γ	Max, 1.71; avg, 1.690–1.695.	Avg, 1.687–1.692.	Max, 1.687.	Max, 1.685.
γ-α(calculated)	0.016–0.021	0.037	0.028	0.032.
γ-α(Berek compensator).	0.019	0.019	0.021	0.018.
$Z\wedge C$	17°±1°	18°±1°	15°±1°	16°±1°.
2V	79°±1°	83°±1°	73°±1°	75°±1°.
Pleochroism:				
X	pgn-y	py-gn	y-gn	pgn-y.
Y	lto-gn	o-gn	med gn	med gn.
Z	gy-gn	gy-gn	med to dk gn	y-gy-gn.

TABLE 11.—*Quantitative spectrographic analyses of hornblende from the Ute Mountains*

[Analyses, in percent, by K. V. Hazel]

Field sample	EMS-74-52	56-E-37	56-E-105	56-E-223
Laboratory No.	151063	151064	151065	151066
Cobalt	0.005	0.006	0.007	0.006
Chromium	.0007	.002	.002	.002
Lithium	.0007	.0015	.0006	.0007
Nickel	.002	.0018	.0021	.0023
Vanadium	.04	.04	.05	.06

TABLE 12.—*Semiquantitative spectrographic analyses of hornblende from the Ute Mountains*

[Analyses in percent, by K. V. Hazel. Looked for but not detected: P, Ag, As, Au, Bi, Cd, Ce, Cs, Dy, Er, Eu, Gd, Ge, Ht, Hg, Ho, Ir, La, Lu, Nb, Nd, Os, Pd, Pr, Pt, Rb, Re, Rh, Ru, Sb, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W]

Field sample	EMS-74-52	56-E-37	56-E-105	56-E-223
Laboratory No.	150163	150164	150165	150166
Boron	0.003	0.003	0.003	0.003
Barium	.007	.007	.007	.003
Beryllium	.00007	------	------	.00007
Cobalt	.007	.007	.007	.007
Chromium	.0007	.0015	.0015	.0015
Copper	.00015	.00007	.00007	.00015
Gallium	.0015	.0015	.0015	.003
Indium	.0007	.0007	.0007	.0003
Lithium	.0007	.0015	.0007	.0007
Molybdenum	.0007	.0007	.0007	.0007
Nickel	.0015	.0015	.003	.003
Lead	.0015	.0015	.0015	.0015
Scandium	.003	.003	.003	.003
Tin	.003	.003	.003	003
Strontium	.015	.015	.007	.03
Vanadium	.03	.03	.07	.07
Yttrium	.003	.0015	.0015	.0015
Zinc	.015	.007	.007	.007
Zirconium	.007	.003	.003	.007

The data suggest that the phenocrysts of hornblende and the hornblende inclusions in the Ute rocks are either inherently similar and have a common origin, or that physical-chemical equilibrium was nearly attained between the magma and xenolithic material that now forms the hornblende inclusions. Hornblende from igneous rocks of the Henry Mountains in Utah have been analyzed by Engel (1959). Engel's chemical and spectrographic analyses indicate that hornblende from the Henry Mountains contains less SiO_2 and MgO than hornblende from the Ute Mountains and generally contains more FeO and Fe_2O_3. Engel (1959, p. 974, 979) pointed out that hornblende from the inclusions in the Henry Mountains is relatively enriched in magnesium, chromium, and nickel. The FeO : MgO ratio for an inclusion hornblende is much lower than in four of the five hornblende phenocrysts. Engel (1959, p. 979) concluded: "The possibility that these inclusions represent early hornblende-rich segregations is appealing because this would readily explain (1) the overlap in composition of phenocrysts and inclusion hornblendes, (2) the relative enrichment of Mg, Cr, and Ni in most of the inclusion hornblendes, and (3) the constancy of mineralogy in the inclusions, and (4) their abnormally high hornblende content (80–95 percent in many inclusions)."

The differences noted by Engel are not apparent in the hornblende from the Ute Mountains. The FeO : MgO ratios are nearly constant (table 8) and are very close to the ratio for the inclusion hornblende of the Henry Mountains (Engel, 1959, p. 974, 979); furthermore, no consistent differences in chromium and nickel content are apparent between phenocrysts and inclusion hornblende from the Ute Mountains (table 11). The similarities are especially significant in view of the fact that the four samples were taken from four chemically and mineralogically different rocks. The hornblende phenocrysts (table 8, samples 1 and 2), are from different laccoliths composed of diorite porphyry. Sample 1 is from hornblende-rich diorite porphyry that contains no pyroxene; sample 2, on the other hand, is from diorite porphyry that contains about 5 percent augite as phenocrysts, as well as about 7 percent hornblende as phenocrysts. Sample 3 is hornblende from an inclusion that has a strong gneissic structure and that contains nearly as much augite as hornblende. This inclusion is from granodiorite porphyry of the northern type, a rock that contains about 5 percent more SiO_2 and 1 percent more K_2O than is average for diorite porphyry. Sample 3 is from granodiorite of the southern type; from a massive inclusion consisting of more than 90 percent hornblende and no pyroxene. This granodiorite (sample 11, table 3) contains more Na_2O and SiO_2 than do rocks classed as diorite porphyry, and much less MgO, CaO, and total iron. Thus the hornblende data do not clearly indicate whether the hornblendic inclusions are fragments of early differentiates, unfused fragments of a substratum that melted to give rise to the magma, or fragments of rocks invaded by the magma. The chemical similarity of the hornblende in phenocrysts and that in inclusions may result from the attainment of chemical equilibrium between inclusions and magma prior to or during the rise of the magma.

The occurrence of schistose or gneissic fabric in many inclusions in the Ute Mountains (see, for example, fig. 10) suggests that the inclusions are unfused fragments from a substratum that gave rise to the magma by anatexis, as suggested by Waters and Hunt (in Hunt, 1958). The occurrence of granophyre and amphibolite in the same inclusion (fig. 10) suggests that the same substratum yielded both hornblende inclusions and the relatively rare inclusions of granophyre.

That the Ute magma may have originated by anatexis, at least in part, is suggested also by the occurrence of anhedral zircon crystals in the intrusive masses in and around Ute Peak. These zircons have subrounded outlines suggestive of mechanical abrasion and a sedimentary history rather than a single-cycle igneous origin. The differentiation toward more silicic magmas through time as indicated in the rock series suggests, however, that laccolithic intrusions would have been only partly contemporaneous, if at all, with the anatectic process. Differentiation seems to best explain the progression of igneous rocks from gabbro to quartz monzonite, and it seems possible that such a process could have taken place after a magma formed by the fusion of a substratum rich in hornblendic material.

STRUCTURAL GEOLOGY AND FORMS OF THE IGNEOUS BODIES

GENERAL FEATURES

The largest structural features in the Ute Mountains area are Ute dome, the result of igneous intrusion, and McElmo dome, which may be partly of igneous origin. The central part of Ute dome is occupied by 3 stocks and approximately 40 major igneous bodies, most of which are laccoliths of diorite and granodiorite porphyry intruded into the Mancos Shale. The largest and topographically the highest intrusive body forms Ute Peak in the northeastern part of the Ute dome (pl. 1).

Faults occur on the northern, western, and southern flanks of Ute dome, and on the southwestern flank and in the central part of McElmo dome. These faults are described in detail in the discussions that follow.

UTE DOME

The configuration of the flanks of Ute dome is shown on plate 1 by structure contours at the base of the Mancos Shale. The dome is probably entirely the result of injection of magma, and principally of three stocks at "The Knees," Black Mountain, and Ute Peak. Because the base of the Mancos Shale is not exposed near the stocks and because the Mancos contains few marker beds there, the structure near the stocks is open to several interpretations. For this reason, the central part of the dome was not contoured on plate 1 and the inferred structure is shown only by cross sections.

Ute dome is nearly circular in plan view and averages about 10 miles in diameter. On its western side, the dome merges with west- and southwest-plunging folds, and its western edge is poorly defined. A broad nose on the southwest flank of the dome may be underlain by a large tongue-shaped intrusive mass, and a broad bifurcate anticline that plunges westward from the northwest flank of the dome may also be underlain by an igneous mass, at least in part.

Other folds along the western flank do not appear to be closely related to igneous activity. They are closely associated with zones of fracturing that may be tectonic and unrelated to igneous activity.

Two smaller structural domes along the southern and southeastern flanks of the Ute dome are called Sentinel Peak dome and Towaoc dome respectively. The Sentinel Peak dome lies about half a mile south of Sentinel Peak. It has about 900 feet of structural relief and has been breached by erosion. Upper beds of the Junction Creek Sandstone are exposed in the central part of the dome, and these beds are cut by a small dike of granodiorite porphyry that is connected to a miniature laccolith intruded into the Recapture Shale Member of the Morrison Formation (dike and laccolith not shown on pl. 1). The Sentinel Peak dome almost certainly overlies an intrusive igneous body. This body probably was fed from "The Knees" stock, or possibly directly from the fissure that fed "The Knees" stock.

The top of Towaoc dome is flat and the sides slope gently. Configuration of the dome and its proximity to the mountains strongly suggest that it is also due to igneous intrusion, possibly at only moderate depth.

The relief on the flanks of Ute dome varies as a result of regional structure. About 3 miles south of Sentinel Peak, near the 5,300-foot structure contour (pl. 1), the dip of the Juana Lopez Member of the Mancos Shale steepens. If this locality is the southern extremity of the Ute dome, there is about 2,000 feet of relief on the south flank of the structure. East of the mountains the regional dip is eastward and southeastward into the San Jaun structural basin. The dip steepens about 2 miles east of the exposed igneous rock of the East Horse laccolith, between the 5,900- and 5,800-foot structure contours. Here, there is a minimum of 1,200 feet of relief, excluding the central part of Ute dome, which was not contoured.

On the northeast, due to the juxtaposition of McElmo dome, the relief is only about 400 feet in the vicinity of Ute Peak. The relief increases westward to about 800 feet on the northwest flank of Ute dome and to more than 1,500 feet on the western flank.

The interpretation of doming of the Dakota in the vicinity of Black Mountain (section *C–C′*, pl. 1) is based on altitudes of the Point Lookout Sandstone exposed on the northern flank of the mountain, and on the altitude of the Juana Lopez Member of the Mancos Shale on the southeast and southwest flanks. The outcrop of the Juana Lopez Member on the southwest flank, west of Pack Trail laccolith, indicates that the top of the Dakota Sandstone may be as high as 7,800 feet near the contact with the Black Mountain stock. Altitudes of the basal part of the Point Lookout Sandstone in the vicinity of "The Knees" stock indicate the top of the Dakota Sandstone near the contact with igneous rock cannot be much higher than 7,000 feet (section *A–A′*, pl. 1). The structural relief at "The Knees" could be greater than that shown in section *A–A′*, but only in a very narrow strip adjacent to the walls of the stock.

The structure shown in the vicinity of Ute Peak (section *B–B′*, pl. 1) is based on altitudes of the Juana Lopez Member of the Mancos Shale exposed east of Ute Peak on North Ute Peak laccolith and from elevations on the base of the Point Lookout Sandstone exposed between Ute Peak and Mable Mountain.

The Juana Lopez Member is about 475 feet above the base of the Mancos Shale in the Ute Mountains area. The structure north of Ute Peak was determined by subtracting the exposed thickness of the north Ute Peak laccolith from elevations on the base of the Juana Lopez Member. Inasmuch as the base of the laccolith is not exposed, the top of the Dakota Sandstone may be lower in the vicinity of the syncline shown on plate 1.

The configuration of the Ute dome at greater depths, such as on the Paradox Member of the Hermosa Formation, probably differs considerably from the configuration on the Dakota Sandstone. In general, at the Paradox horizon there would probably be fewer underlying conformable intrusive masses and the doming would be due almost entirely to the insertion of the stocks. This difference could result in three domes of small diameter but having steep sides; therefore, structural relief greater than that on the Dakota Sandstone may occur on the Paradox Member in the vicinity of the stocks. This conclusion is based also on observable relations in the Henry Mountains of Utah where stocks that are very similar to the Ute stocks are in contact with beds as old as Permian.

Hunt (in Hunt and others, 1953, p. 139–141) proved that the doming on each of the stocks of the Henry Mountains is directly proportional to the diameter of the stock. His deductions may also be applicable to the Ute Mountains; however, several buried, probably conformable intrusive bodies are thought to underlie the Dakota Sandstone at shallow depths in the Ute dome, and an accurate analysis to determine the doming caused only by the emplacement of the stocks is impossible.

McELMO DOME

McElmo structural dome is just north of the Ute Mountains, and only the southern half of it lies within the mapped area. Its structure is well exposed in McElmo Canyon, which cuts through the southern flank (pl. 1).

The central part of the dome is nearly star-shaped in outline and has a flat top. The dome is asymmetric, its steepest side being on the south where the maximum dip is about 9½°. Except for the south side, the flanks of the dome pass into a series of five anticlines. A northwest-trending anticline that lies north of the mapped area is 7 miles long (Coffin, 1920). An east-trending anticline near the northern border of the mapped area extends more than 12 miles from the east side of McElmo dome and passes through the city of Cortez, Colo. A moderately sharp anticline plunges southeastward from McElmo dome in the vicinity of Ute Peak. It is asymmetric with a steeply dipping southwest side. Because of the uncertainties in recognizing stratigraphic levels in the poorly exposed Mancos Shale, the structural saddle between this anticline and Ute Peak may be considerably higher or lower than shown on plate 1.

A poorly defined anticline extends southwest from McElmo dome about 4 miles, almost parallel to a graben that lies to the north. The fifth anticline of the series (not shown on pl. 1) extends northeast of McElmo dome and can be traced for approximately 6 miles.

The total area affected by McElmo dome and its satellitic anticlines is about 20 miles east to west and 10 miles north to south. If the configuration of the southeast-trending anticline in the vicinity of Ute Peak is correctly shown on plate 1, the McElmo structure has about 500 feet of closure; the 6,600-foot contour is the lowest closing contour.

The origin of McElmo dome and its relation to Ute dome is uncertain. The proximity of the two domes suggests that McElmo dome may also be underlain by an igneous mass. The two domes are of about the same areal extent, and appear to have about the same structural relief. McElmo dome differs from Ute dome mainly in the configuration of its satellitic folds. The McElmo structure is characterized by long, relatively narrow anticlines that plunge radially away from the central structure, whereas Ute dome is characterized by broad flexures that lose definition at short distances from the central structure. Anticlines similar to those around McElmo dome occur only on the western flank of Ute dome and, as previously mentioned, may not be genetically related to the Ute structure.

An oil well (The Three States Natural Gas Co. (Byrd-Frost) MacIntosh 1) drilled into the central part of the McElmo structure cuts igneous rock from a depth of 4,600 feet to the bottom of the hole at 4,965 feet. According to Zabel (1955, p. 135), the igneous rock from 4,600 to 4,715 feet was identified as either a dellenite or a latite, and the rock from 4,715 to 4,965 feet as a porphyritic hornblende monzonite. Such rocks could be related to those of the Ute Mountains. The igneous rocks apparently were intruded into the Paradox Formation of Pennsylvanian age at a point 90 feet below the highest anhydrite. In contrast, two gas wells drilled farther north, the Schmidt 1 and the Dudley 1, which bottomed in Devonian and Cambrian strata, respectively, did not cut igneous rock. Similarly, no intrusive rocks were found above the granite of Precambrian age in the Gulf Oil Co. Fulks 1, on the northeast flank of McElmo dome, 6 miles northeast of Goodman Point (pl. 1). The possibility exists, therefore, that the igneous rock in the MacIntosh 1 is part of a laccolithic body extending northward from the Ute igneous centers. Most of the structural relief of McElmo dome and its satellitic folds may be a result of basement uplift related to Late Cretaceous or early Tertiary folding, such as recognized elsewhere on the Colorado Plateau (Hunt, 1956, p. 57–58). The possibility also exists that part of the relief is due to movement of salt. According to Zabel (1955, p. 134), the thickness of the salt section in the Paradox varies considerably in the McElmo area. The salt is 1,500 feet thick in the Three States Schmidt 1; 1,350 feet thick in the Three States Dudley 1; and only 1,155 feet thick in the Gulf Fulks 1. There is an overall thinning of 345 feet from the Schmidt 1 on the highest part of McElmo dome to the Fulks 1 on the northeast flank.

FAULTS

Steeply dipping normal faults occur in the Ute Mountains area on the south, southwest, and northwest flanks of Ute dome, on the southwest flank of McElmo dome, in the central part of McElmo dome, and along the anticline trending eastward from McElmo dome. Faults are conspicuously absent on the steeply dipping east flank of Ute dome.

The greatest concentration of faults is on the northwest flank of Ute dome. Two sets of faults appear to have formed simultaneously in this vicinity; one set strikes nearly west, the other set northeast. The west-striking faults parallel west-trending folds and have displacements that rarely exceed 30 feet.

The northeast-trending faults appear to be extensions of a zone of faulting that cuts the southwest flank and the central part of McElmo dome. This zone curves to a nearly east strike in the vicinity of the Schmidt 1 gas well on McElmo dome and continues eastward beyond the map area toward Cortez, Colo. The faults along this zone form a graben on the southwest flank of McElmo dome and have displacements of as much as 180 feet, the greatest known in the Ute Mountains area. Faults along the graben contain radioactive mineral deposits, described on pages 62–64.

The northeast-trending faults are roughly concentric with the northern part of the Ute Mountains and may be related to the uplift of Ute dome. On the other hand, they are nearly parallel to southwest-plunging folds in the western part of the area that may predate the doming, and to inferred fracture zones that predate intrusion, which is the presumed cause of doming. The two largest stocks, at Black Mountain and Ute Peak, lie suggestively close to and parallel with the southwestward extension of the fracture and fault along which the Ute Creek dike was intruded (pl. 1). It is conceivable, therefore, that the extensive zone of northeast-trending faults lies en echelon to a zone of fracturing that localized part of the igneous activity in the Ute Mountains and also the uplift of McElmo dome.

"The Knees" stock appears to have been intruded along a north-northwest zone of fracturing along which several dikes have also been intruded. This zone of fracturing extends south of the Sentinel Peak dome and apparently controlled the location of the inferred intrusive mass of Sentinel Peak dome. Two dominant zones of intrusion apparently were localized by preexisting fractures—a northeast zone and a north-northwest zone. Black Mountain may actually lie at the intersection of the two zones.

INTRUSIVE BODIES

Most of the intrusive bodies in the Ute Mountains were probably injected from three stocks: Black Mountain, "The Knees," and Ute Peak along conduits parallel to the bedding of the sedimentary rocks. The stocks are of small diameter and are less extensive areally than some of the laccoliths. Except at Ute Peak, the stocks are composite intrusive bodies containing several rock types. The stocks appear to have discordant sides, but they probably lifted roofs of sedimentary rocks upward during intrusion, for doming of Mancos strata around the stocks is very slight. The igneous rock exposed on Ute Peak may be part of a bysmalith that overlies a stock of smaller diameter.

A common feature of diorite porphyry and granodiorite porphyry of the northern type in the Ute Mountains is the linear orientation shown by hornblende phenocrysts. The linear orientation was not studied in all intrusive bodies, but observations in a few laccoliths indicate consistent trends that are inferred to be parallel to the flow direction of the magma. As many as 10 readings were made on exposures which offered observation on 3 approximately perpendicular surfaces, and the readings were averaged to give those plotted on plate 1. The more conspicuous the lineation, the fewer the readings necessary and the greater agreement between them. No fewer than four separate readings were averaged at any one point. The individual readings at each outcrop rarely spanned an arc of 20° in either direction or plunge.

Planar orientation of minerals was observed within a few feet of the margins of laccoliths and is interpreted as a primary flow structure. It is defined by a predominance of hornblende phenocrysts oriented in a common plane. The orientation is rare and vague because of the lack of platy minerals such as biotite and tabular feldspar through most of the intrusive bodies. In a few places, linear flow structure was observed in the plane of the planar flow structure.

Rock cleavage as mapped on plate 1 is defined by closely spaced low-angle jointing that is thought to parallel the original sides and roofs of laccoliths. In contrast to the planar flow structure, the rock cleavage appears to cut mineral grains and probably formed by contraction during cooling, parallel to the original sides and roofs of the laccoliths.

STOCKS

BLACK MOUNTAIN STOCK

The Black Mountain stock is in the north-central part of Ute dome and is approximately 1¼ miles in diameter. It is composed of granodiorite porphyry of the northern type, biotite-rich quartz monzonite porphyry, and diorite porphyry. Although no microgabbro is exposed, the stock probably fed microgabbro into the sills exposed on the flanks of the mountain. The granodiorite porphyry in the stock has a nearly doughnut-shaped outcrop pattern and completely encloses a composite mass of baked Mancos Shale, diorite porphyry, and quartz monzonite porphyry. The diorite porphyry is older than the granodiorite, which in turn is older than, and has been intruded by, quartz monzonite porphyry. The age relation of the granodiorite porphyry and the lamprophyre exposed in the northeastern part of the mountain is not known, for the contacts between the rocks are not exposed.

Shale beds of the Mancos form the "hole" of the granodiorite doughnut (pl. 1). They may be part of a modified roof pendant that bottoms in igneous rock at shallow depth, or they may overlie sedimentary rocks that extend in a roughly cylindrical mass to great depth. The northern, northwestern, and northeastern sides of the intrusive mass are nearly vertical and appear to be entirely discordant against gently dipping beds of Mancos Shale and basal sandstone beds of the Point Lookout. The southern and southeastern sides, on the other hand, appear to be nearly conformable with Mancos strata. Shale exposed a half mile south-southwest of the top of Black Mountain conformably overlies granodiorite porphyry, and shale near the extreme southeastern part of the intrusive appears to extend beneath the intrusive as a floor. Thus the southeastern extremity of the stock may be conformable in part, having both a roof and a floor.

A small neck or miniature stock composed of diorite porphyry crops out in the west-central part of Black Mountain, and a thin sill composed of identical rock crops out a few hundred feet east of the neck. It seems likely that the sill was intruded from the igneous neck.

The Black Mountain stock was probably the feeder for nearly all the intrusive rocks exposed in the north half of the Ute Mountains, with the exception of those at Mable Mountain and Ute Peak, including the satellitic North Ute Peak and East Horse laccoliths. As shown on plate 1, intrusive bodies surround Black Mountain radially, and most of those that lie northwest, west, and southwest of Black Mountain have, respectively, southeast-, east-, and northeast-trending hornblende lineation. The lineation suggests that the intrusive masses were fed from Black Mountain along flat-lying conduits. Several flat-lying sills near the west side of Black Mountain may have been feeders for laccoliths lying to the west. Tongue-shaped laccoliths of diorite porphyry and a sill of microgabbro abut against the southwest, southeast, and northeast sides of the Black Mountain granodioritic stock, and it is inferred that these intrusive bodies were originally connected to diorite porphyry and microgabbro within the stock. The paucity of exposed diorite porphyry and the lack of microgabbro in the stock probably is due largely to concealment by granodiorite that surged to a higher level (section *C–C′*, pl. 1) after pressing the earlier rocks against the walls of the stock.

Metamorphism is more intense around the Black Mountain stock than around any of the laccoliths or bysmaliths. The Mancos Shale in and adjacent to the stock has been intensely baked and is intruded by many dikes, but no shattering similar to that described by Hunt and others (1953, p. 90–151) was observed. The width of the marginal baked zone ranges widely. On the east side of the mountain the shale is baked for a distance of more than one-quarter of a mile from the stock. Although exposures are poor on the north and west sides, baking appears to extend considerably less than 1,000 feet from the stock. On the south side of the mountain, baking caused by the stock cannot be distinguished from that caused by nearby concordant intrusive bodies.

The igneous rocks in the Black Mountain stock have been neither intensely altered nor mineralized, and consequently the hornblende and biotite are generally fresh and the plagioclase is clear.

Lineation defined by hornblende crystals in the stock generally plunges at an angle greater than 45°, a steeper angle than those in the laccoliths.

"THE KNEES" STOCK

"The Knees" stock is exposed in the southern part of the Ute dome, a few hundred feet southeast of two small peaks (Hermano peaks, pl. 1) that form the "knees" of Sleeping Ute Mountain. The stock is approximately two-thirds of a mile long and about one-fourth of a mile wide and has nearly vertical sides that cut beds of flat-lying Mancos Shale and Point Lookout Sandstone.

The intrusion of the stock at "The Knees" appears to have been controlled by a north-northwest fracture zone along which many dikes were also intruded. The stock is surrounded by laccoliths, bysmaliths, sills, and dikes, including many small, thin, and discontinuous dikes, only a few of which are shown on plate 1. The small dikes include examples of every igneous rock known in the Ute Mountains.

"The Knees" stock probably had the same succession of magmas as the other stocks in the Ute Mountains, although only granodiorite and diorite porphyry are exposed in the stock proper. The occurrence of microgabbro (not shown in section *A–A′*, pl. 1) and quartz monzonite porphyry at depth in the stock is inferred from exposures of these rocks in minor discordant apophyses at the surface near the stock and from the radial arrangement of larger intrusive masses around the stock. The micogabbro was the most fluid rock intruded in the Ute Mountains, and "The Knees" stock may have been only a thin dike or a small neck when it was emplaced. The microgabbro presumably makes up a very small percentage of the total volume of rock in the stock and, except for minor apophyses, never reached the level of the stock that is currently exposed. Similarly the quartz monzonite porphyry did not reach the exposed level of the stock except as minor apophyses, probably because earlier intrusive rocks occupied most of the available space. The quartz monzonite apparently ascended along fractures that flanked the granodiorite- and diorite-filled stock. "West Toe," for example, is a small neck or boss of quartz monzonite porphyry that vertically crosscuts the surrounding sedimentary rocks and is located between "The Knees" stock and two northeast-trending faults. Banded laccolith, composed of quartz monzonite porphyry, has prominent vertical ridges resulting from weathering of alternating vertical zones of intensely altered and moderately altered rock. The vertically altered zones suggest an underlying feeder perhaps similar to that shown in section *A–A′*, plate 1.

The metamorphism adjacent to "The Knees" stock is more intense than around Black Mountain. The Mancos Shale and basal beds of the Point Lookout Sandstone have been intensely baked for a distance of at least a quarter of a mile from the stock; adjacent to the stock in a zone a few tens of feet to more than 500 feet wide, pyroxene, epidote, sphene, and sparse garnet have crystallized in the shale. In general, the zone of metamorphism around "The Knees" stock is similar to the "shatter zones" around the stocks of large diameter in the Henry Mountains.

UTE PEAK

The Ute Peak intrusive body (pl. 1), composed of hornblende granodiorite porphyry, has a minimum thickness of 2,500 feet. It forms the highest peak in the mountains, is very nearly circular in plan, and is about 1¼ miles in diameter. Vertical or nearly vertical lineation, defined by hornblende needles, is conspicuous in the porphyry in the steep slopes and cliffs of the peak.

Structural relations between the granodiorite and Mancos Shale are obscured by thick talus which almost completely covers the contacts. Poor exposures of Mancos Shale and granodiorite porphyry along the northwest flank of the peak indicate that the shale is only slightly altered adjacent to the igneous rock, and that it dips 20° NW to vertical.

The North Ute Peak laccolith, composed of diorite porphyry, lies north of Ute Peak and appears to have been fed either from the Ute Peak body or from a feeder that underlies Ute Peak. East Horse Laccolith, also composed of diorite porphyry, lies southeast of Ute Peak and has rather consistent southeast-trending hornblende lineation that suggests that the laccolith was fed from the direction of Ute Peak.

The vertical hornblende lineation at Ute Peak and the steep sides of the intrusive mass indicate that Ute Peak is either a stock or a bysmalith. (The term "bysmalith" implies that the intrusive mass raised its sedimentary roof by faulting, but that the faulting did not penetrate below the floor of the mass.) The presence of satellitic intrusive bodies suggests that the body is a stock, but weak metamorphism and alteration as compared with "The Knees" and Black Mountain stocks suggest that it is not entirely a stock. It seems more likely that the Ute Peak body is floored in part and overlies a stock (section *B–B′*, pl. 1).

Ute Peak is comparable to bysmaliths in the Henry Mountains in its size, shape, and ratio of thickness to areal extent. It is strikingly similar to the Table Mountain bysmalith that was probably fed by a lateral feeder (Hunt and others, 1953, p. 141). Particular attention was devoted to the structure of the Mancos Shale between Black Mountain and Ute Peak in an effort to determine if the Ute Peak mass was fed by a lateral conduit like those described by Hunt in the Henry Mountains. Although the exposures are poor, there is no discernible folding of the Mancos strata to indicate a thick feeder. This fact, together with the nearly circular outline and vertical lineation of the Ute Peak body, suggests that the intrusive was fed by a vertical feeder or stock near its center, rather than by a lateral feeder from the Black Mountain stock.

The base of the Ute Peak body is probably above the top of the Dakota Sandstone, as suggested by the lack of sandstone in the talus along the sides of Ute Peak or in the gravel on the benches east of the peak.

BYSMALITHS

SENTINEL PEAK

The Sentinel Peak intrusive mass is composed of granodiorite porphyry of the southern type and is approximately 1½ miles south of "The Knees" stock. It is a bysmalith nearly 2 miles long, three-fourths of a mile wide, and, excluding Sentinel Peak proper, about 800 feet thick. The bysmalith may actually comprise two separate intrusive masses that have coalesced. (See pl. 1.)

Almost all the north side of the bysmalith is in fault contact with Mancos Shale; the south side probably had a similar fault contact, but most of the shale has been removed by erosion. On the east and west sides, the bysmalith is in intrusive contact with older diorite porphyry. At two places along the north side near the top, blocks of Burro Canyon and Dakota strata crop out. These blocks appear to be uplifted parts of the sides and roof.

The base of the intrusive is extremely irregular, being located stratigraphically at various horizons between the base of the Burro Canyon Formation and the Juana Lopez Member of the Mancos Shale. At its southern edge, the base is in the Mancos Shale, probably at a level between the Juana Lopez Member and the Greenhorn Limestone Member. The shale beds are only slightly baked. The blocks of Burro Canyon and Dakota strata that crop out along the north side of the intrusive may mark the locations of two feeders that extended from "The Knees" stock beneath Burro Canyon and Dakota strata and broke upward into Mancos Shale at the bysmalith. Except near these conduits, the bysmalith is probably mostly in the Mancos.

Exposures along the southeast side of the Sentinel Peak bysmalith suggest that the igneous rock was injected in a nearly horizontal southward direction with sufficient force to thrust beds of Mancos Shale over beds of the Brushy Basin Member of the Morrison that had been domed upward by an earlier intrusion. The inferred structural relations are shown in figure 17.

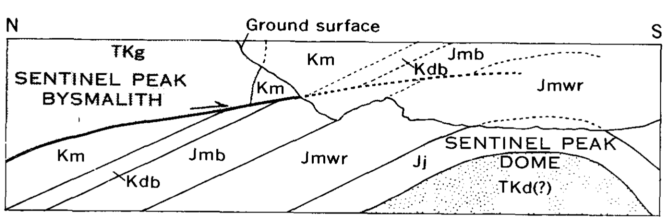


FIGURE 17.—Sketch showing inferred structural relations thought to be the result of igneous intrusion at depth near the contact of the Sentinel Peak intrusive with the Sentinel Peak dome. Not drawn to scale. TKg, granodiorite porphyry; TKd(?), diorite porphyry; Km, Mancos Shale; Kdb, Dakota Sandstone and Burro Canyon Formation; Jmb, Brushy Basin Member, and Jmwr, Westwater Canyon and Recapture Members, all of the Morrison Formation; Jj. Junction Creek Sandstone.

The most conspicuous part of the Sentinel Peak bysmalith is Sentinel Peak itself, a vertical spine that rises 500 feet above the rest of the bysmalith. The spine is part of a dikelike mass that apparently intruded the original roof of the bysmalith, probably along a fracture that was part of the fracture system extending from "The Knees" stock south-southeastward beyond the Sentinel Peak dome (pl. 1). The spine has many vertical ridges formed by differential weathering of alternating zones of moderately and intensely altered rock, and probably served as a conduit or neck that fed magma from the Sentinel Peak bysmalith into overlying sedimentary rocks.

MABLE MOUNTAIN

Mable Mountain, one of the largest single intrusives in the Ute Mountains, is approximately 1 mile northwest of Ute Peak. The mountain is composed of diorite porphyry and has a nearly mushroom shape. It is about 1,500 feet thick in its thickest part and probably overlies the Ute Creek dike.

Beds of Mancos Shale and thin sills of diorite porphyry form the southwest side and part of the top of Mable Mountain. The base of the intrusive body is not exposed on the north side, where contacts with the Mancos Shale are buried by thick talus. The base of the body is only a few tens of feet above the top of the Dakota near the north side of Mable Mountain, but is several hundred feet above this level a few hundred feet southward along Pine Creek.

On its northeast and north sides, the bysmalith is probably in fault contact with Mancos Shale, for the shale is greatly brecciated and the sides of the intrusive mass are very steep. The south side is probably also faulted, although no faults were seen during mapping. The base of the Point Lookout Sandstone crops out at about the 8,400-foot contour (pl. 1) near the highest part of Mable Mountain. Only 1,500 feet to the north, igneous rock crops out at or near the same elevation, and a little farther north, roof rocks of the intrusive include beds of the Greenhorn Member in the basal part of the Mancos Shale. A fault must lie between the Point Lookout Sandstone and the igneous mass, probably at the contact of shale and diorite porphyry as shown on plate 1.

The Ute Creek dike probably was the feeder for the Mable Mountain intrusive rock and may be connected to the Black Mountain stock at depth.

Much of the diorite porphyry of Mable Mountain has been intensely altered and mineralized with pyrite, especially in the western part of the body. Reddish iron stain produced by the oxidization of pyrite attracted many prospectors to the area during the early 1900's.

THE "WEST TOE"

The "West Toe" body of quartz monzonite porphyry is a small discordant body intruded through gently dipping beds of the Dakota Sandstone and Mancos Shale. It is called a bysmalith because the discordant side contacts suggest that the intrusive lifted its roof, but nothing is known regarding the floor. The body is structurally very similar to that of Sentinel Peak (the "East Toe"), and probably was a feeder for igneous rock intrusive into overlying sedimentary beds.

LACCOLITHS

NORTH UTE PEAK LACCOLITH

The North Ute Peak laccolith is nearly continuous with the north side of the Ute Peak bysmalith and extends half a mile north from Ute Peak. It is about 600 feet thick and a little more than a mile wide. It consists of leucocratic diorite porphyry that is generally similar to porphyry in Ute Peak bysmalith but contains less potassium feldspar.

North Ute Peak laccolith was intruded into the Mancos Shale near the base of the Juana Lopez Member, or about 475 feet stratigraphically above the base of the Mancos. It is believed to have been intruded from the same source as Ute Peak and to be concordant. Much of the laccolith lies astride the southeastward-trending syncline between the Ute Mountain mass and McElmo dome (pl. 1).

HORSE MOUNTAIN LACCOLITH

Horse Mountain laccolith is east of Cottonwood Creek and about 1¼ miles directly south of Ute Peak. It is composed of leucocratic diorite porphyry which is petrographically similar to the granodiorite porphyry of Ute Peak except for a lack of abundant potassium feldspar.

The laccolith is elongated east-southeast and is about 1 mile long and not more than half a mile wide. The roof has been removed and only the sides of the laccolith are preserved, but the top of Horse Mountain is thought to be near the original top of the laccolith. The laccolith is at least 1,100 feet thick and, because its horizontal dimensions are small, it has very steep sides, parts of which may be faulted.

Two alined vertical dikes a few hundred feet south of Horse Mountain are probably upward offshoots from the concealed wedge-edge of the laccolith, as probably are dikelike bodies on the northeast side.

Linear flow structure is well displayed in most outcrops. As in other laccoliths composed of hornblende-bearing diorite porphyry, the flow structure is exhibited by alined phenocrysts of hornblende. Except in places at the ends of the laccolith, the lineation is oriented to the east-northeast and suggests flow in that direction. This lineation, together with the proximity to the Black Mountain stock, the elongation of the laccolith toward the east-southeast, and the structural setting at its west end, suggests that the laccolith was fed laterally from the Black Mountain stock.

EAST HORSE LACCOLITH

East Horse laccolith is composed of normal diorite porphyry and is east of Horse Mountain. In plan view it is oval, elongated N. 80° E., and is about 1½ miles long and 1 mile wide. It is at least 350 feet thick in the center and tapers gradually to gently rounded sides. It forms a low topographic dome that is dissected by two east-trending canyons, neither of which has penetrated underlying sedimentary strata. The laccolith is in Mancos Shale.

Many readings of primary flow structure as defined by hornblende phenocrysts were taken in East Horse laccolith. Two consistent trends were noted: in the northern part of the laccolith, lineations plunge about 15° toward the east-southeast, and in the southern part they plunge gently north or south, or are horizontal. These trends suggest that two separate intrusions occurred.

The source appears to have been under the Ute Peak bysmalith (section *A–A′*, pl. 1), although the laccolith may have been fed from the Black Mountain stock, or from both stocks. Flow structure suggests that the feeder was almost flat lying.

The Razorback laccolith intruded and uplifted part of the south edge of East Horse laccolith, and thus is the younger of the two. The straight, north side of the Razorback laccolith clearly reflects the influence and control of the earlier East Horse laccolith to the north.

SUNDANCE CLUSTER OF LACCOLITHS

Laccoliths of the Sundance cluster are all composed of the normal type of diorite porphyry, and all were intruded into the Dakota Sandstone or the lowermost part of the Mancos Shale at about the same time. The cluster includes the Sundance, East Sundance, Trapdoor, and Irwin laccoliths southeast of Black Mountain. The Trapdoor laccolith is west of Sundance laccolith, and Irwin laccolith (not shown on pl. 1) is east of the East Sundance laccolith. All four laccoliths probably are offshoots of the Black Mountain stock, through concordant conduits in the strata stratigraphically lower than the laccoliths. All members of the group have flat tops and, with the possible exception of the Irwin laccolith, the base of which is not exposed, average about 350 feet in thickness.

The floors of the four laccoliths probably are at or near the Dakota-Mancos contact. With the exception of the Irwin laccolith, the roofs of the laccoliths are

Dakota Sandstone in some places and Mancos Shale in others (pl. 1). Large blocks of Dakota Sandstone apparently were tilted upward by the rising magma in a manner analogous to the tilting of a trapdoor, and magma then spread into the overlying Mancos Shale (fig. 18).

RAZORBACK LACCOLITH

The Razorback laccolith is in part contiguous with the south edge of the East Horse laccolith. It is oval in plan view, elongated N. 80° W., and measures 1 mile in length by a maximum of 0.4 mile in width. The abrupt western end has a minimum thickness of 300 feet. The greatest original thickness of the laccolith was probably 850 feet in the central part. The roof of Mancos Shale is missing over all the crestal part of the laccolith but can be seen on the north side.

The southern part of the laccolith was intruded into the Mancos Shale about 100 feet above the Greenhorn Limestone Member. Along its north side the laccolith is somewhat discordant, and is in contact with stratigraphically lower beds from west to east. In its western third, the base of the laccolith lies as much as 100 feet above the Greenhorn Limestone Member of the Mancos. On the northeast the base of the laccolith lies below the top of the Dakota (pl. 1).

The linear flow structure defined by alined phenocrysts of hornblende indicates a general southeastward movement of the magma in the western part of the Razorback body, an eastward flow in the central part, and an east-northeastward flow in the eastern part. This laccolith was probably fed from the Black Mountain stock by a conduit that was structurally and stratigraphically lower than and directly under, or just to the south of, the Horse Mountain laccolith. The conduit probably lies about 100 feet above the base of the Mancos.

LAST SPRING LACCOLITH

The Last Spring laccolith is exposed over a broad area east of "The Knees" stock and south of the Sundance cluster of laccoliths. The long dimension of this laccolith trends northeastward. The laccolith is as much as 1 mile wide, and is about 750 feet thick in its central part.

The roof of the laccolith is composed of Dakota Sandstone and Mancos Shale. The fact that beds of the Dakota are exposed at the top of the laccolith and along the west side suggests a trapdoor effect similar to that described for the Sundance cluster of laccoliths. The southwest end of the laccolith is in contact with "The Knees" stock. This relation, together with the orientation of the body, suggests that the laccolith was fed laterally from the stock.

The Last Spring laccolith consists of granodiorite porphyry of the southern type, but contains more phenocrysts of quartz and crystals of epidote than most of this rock. A petrographically similar rock crops out a few hundred feet east of the Last Spring laccolith, on slopes west of Towaoc, Colo. This rock forms a flat-topped laccolith in mudstone beds of the Brushy Basin Member, and probably came from the conduit that supplied the Last Spring laccolith.

FLAT LACCOLITH

Flat laccolith is in contact with the south side of the Last Spring laccolith, which cut and uplifted parts of it. To the south, Banded laccolith has also cut and uplifted parts of Flat laccolith.

Flat laccolith is 1½ miles in length by a maximum of one-third mile in width and is estimated to be 250 to 300 feet thick; its long dimension trends southeast. The laccolith is flat-topped and has tapered sides. It was intruded into the lower few hundred feet of the Mancos Shale throughout its length, but is stratigraphically lower toward the southeast. Wherever exposures are good, the contact appears concordant and the nature of the downward crosscutting is not known.

Flat laccolith was fed from "The Knees" stock to the northwest, as indicated by the northwest trend of linear flow structure. (See pl. 1.)

THREE FORKS LACCOLITH

Three Forks laccolith is composed of normal diorite porphyry and is approximately half a mile southeast

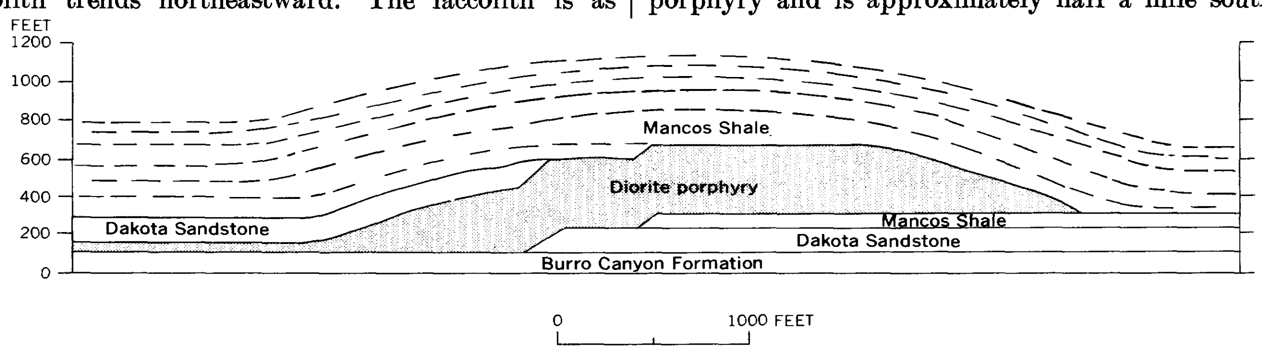


FIGURE 18.—Sketch showing inferred stratigraphic and structural relations of laccoliths in the Sundance cluster, and mechanism of "trapdoor" structure.

of "The Knees" stock. It is bounded on the southwest and southeast by younger intrusive masses of granodiorite and quartz monzonite. Alined hornblende crystals in this hornblende-rich porphyry define a general southeast trending lineation which strongly suggests that the magma came from "The Knees" stock.

A conspicuous feature of Three Forks laccolith is the pronounced alteration of its central part. Phenocrysts of hornblende and plagioclase have been almost completely altered to secondary minerals, whereas those near the margins are clear and fresh. The alteration was evidently caused by solutions and vapors that accumulated in the central part of the igneous mass, probably immediately following consolidation. The alteration thus is considered to be deuteric and is the best known example of this type of alteration in the Ute Mountains.

BANDED LACCOLITH

Banded laccolith, immediately southeast of Three Forks laccolith, is composed of quartz monzonite porphyry. It is half a mile wide and originally was a mile long, but the southeastern third has been separated from the main body by erosion. The central part of the laccolith is 550 feet thick; considering the lateral dimensions, this is thicker than most laccoliths composed of diorite porphyry. Most of the northwestern part of the laccolith was intruded into a zone ranging from 100 feet below the Dakota-Mancos contact to just above the contact. The southeastern third intruded the Mancos near the level of the Greenhorn Limestone Member.

The bare, steep-faced outcrops of the quartz monzonite porphyry display impressive vertical banding. The banding is due to weathering of unevenly altered vertical layers that are interpreted as flow structure. In the strongly altered layers, hornblende is replaced by chlorite and magnetite, and plagioclase by kaolinite and abundant calcite. The alteration is probably deuteric. Unaltered rock occurs within short distances of the contacts with the sedimentary rocks.

As shown on plate 1, the flow banding in the northwestern part of the laccolith strikes generally northwest and dips slightly southwest or as much as 45° NE. In detail, the attitude of the banding is much more diverse than the map indicates, and is more erratic in the southeastern part of the laccolith than in the northwestern part.

THE "WEST TOE" CLUSTER OF INTRUSIVE BODIES

The "West Toe" cluster includes several intrusive bodies between "West Toe" bysmalith, "The Knees" stock, and the western part of Mushroom laccolith. The major intrusive bodies in this area are tongue-shaped laccoliths composed of normal diorite porphyry that were intruded into Mancos Shale a few tens of feet above the top of the Dakota Sandstone. The laccoliths were probably intruded laterally from "The Knees" stock. Numerous sills crop out in the area between the laccoliths and "The Knees" stock and are stratigraphically above the laccoliths. There are also many dikes of granodiorite porphyry, several of which cut sills and laccoliths of diorite porphyry.

MUSHROOM LACCOLITH

Mushroom laccolith is near the center of the Ute Mountains midway between "The Knees" stock and the Black Mountain stock and is composed of the central type of granodiorite porphyry. It is 2¼ miles long and almost 1 mile wide. A thickness of about 500 feet is exposed but, because the base is not exposed, the total thickness is not known. The laccolith lies in the Mancos Shale. It may have been fed laterally from either Black Mountain or "The Knees," or it may have had a nearly vertical conduit connected to a stock at considerable depth.

Many dikes radiate outward from the approximate center of the Mushroom laccolith. The dike rocks contain crystals of andesine as much as 10 mm in length and resemble the southern type of granodiorite porphyry more closely than the central type. As shown by thin sections, the dikes contain less quartz than the granodiorite of the laccolith.

PACK TRAIL LACCOLITH

Pack Trail laccolith, composed of diorite porphyry, is between Mushroom laccolith and Black Mountain in secs. 34 and 35, T. 35 N., R. 18 W. The laccolith was intruded into Mancos Shale below the Juana Lopez Member. Sedimentary rocks have been almost completely removed from the flanks of the laccolith; only a few remnants remain. These remnants dip steeply, but the fact that the top surface of the intrusive body is conformable with them suggests a laccolith rather than a bysmalith. The base of the laccolith is exposed for a few feet in a deep valley cut into it by a tributary of Cottonwood Creek in N½ sec. 35, T. 35 N., R. 18 W. The laccolith is 1¼ miles long, about 1 mile wide, and at least 700 feet thick. It was probably fed from the Black Mountain stock, which is contiguous on the north.

TONGUE LACCOLITH

Tongue laccolith is exposed a few hundred feet east of Mushroom laccolith and about half a mile northeast of "The Knees" stock. It is composed of microgabbro porphyry and is tongue-shaped in plan. It probably was intruded laterally from "The Knees" stock. It is about 200 feet thick, half a mile wide, and of unknown length.

The laccolith has been intruded by a younger and smaller laccolith of diorite porphyry, and has been domed upward along its southern extremity by granodiorite porphyry of the Last Spring laccolith. It is also cut by a dike of granodiorite porphyry.

YUCCA CLUSTER OF LACCOLITHS

The Yucca cluster of laccoliths lies west and southwest of Black Mountain. Laccoliths of this cluster are composed of diorite porphyry of the normal type. They have distinct northeast-trending lineation, extend almost to Black Mountain, and probably were intruded laterally from the Black Mountain stock.

With the exception of a small laccolith in the southern part of sec. 33, T. 35 N., R. 18 W., the laccoliths were intruded into Mancos Shale above the Juana Lopez Member. The laccoliths average less than 300 feet in thickness.

"THE BUTTES" LACCOLITH

"The Buttes" laccolith is about 2 miles northwest of the top of Black Mountain. It has the shape of a crude equilateral triangle and is about a mile long. It is asymmetric in cross section, and is thickest (about 500 feet) in the northwestern part.

The southern part of the laccolith was intruded some 200 feet above the base of the Mancos, the northern part within 100 feet of the base, and the western part at or below the top of the Dakota. Inasmuch as the laccolith was probably fed from the south and southeast through a sill-like conduit from Black Mountain, the magma evidently cut downward stratigraphically in its advance toward the northwest.

NORTH BLACK MOUNTAIN LACCOLITH

North Black Mountain laccolith, composed of normal diorite porphyry, is southwest of Mable Mountain and northwest of Black Mountain stock. It is elongate to the north and about 2 miles long; the north half is about three-fourths mile wide but the south half is narrower. The laccolith has a maximum thickness of about 700 feet, in the south-central part.

On the southwest, the thin edge of the laccolith lies several hundred feet above the base of the Mancos Shale, but farther north along the west side, it lies in the upper 100 feet of the Dakota Sandstone. Because of poor exposures, the nature of the northward change in stratigraphic level is not known.

The steeply dipping east side of the laccolith is well exposed. There, Mancos strata dip 30° away from the laccolith and can be traced upward into a nearly flat roof (pl. 1). On the south, toward Black Mountain, the fact that the Mancos dips as much as 30° away from North Black Mountain suggests that the laccolith bulges as it approaches Black Mountain stock.

SILLS AND DIKES

Near the head of Pine Creek between Black and Mable Mountains are several sills composed of microgabbro and diorite porphyry rich in mafic minerals; two of these sills are shown on figure 19. Field relations indicate that the sills were domed locally by the emplacement beneath them of the North Black Mountain laccolith and Mable Mountain bysmalith, which consist of more silicic rocks.

Many dikes occur in the Ute Mountains, especially in the vicinity of "The Knees" stock and the Black Mountain stock. Most of the dikes are composed of granodiorite porphyry, and several of these cut sills or laccoliths composed of diorite porphyry. The longest dike in the mountains is the Ute Creek dike, which extends northeastward from the base of Mable Mountain to McElmo Creek (pl. 1). This dike was probably the feeder of the Mable Mountain bysmalith.

BRECCIA PIPES

Several breccia pipes cut the Mancos Shale in the extreme western part of the Ute Mountains, in secs. 31 and 36, T. 35 N., Rs. 19 and 18 W. The pipes crop out a few feet below the projected base of the westernmost and largest laccolith in the Yucca cluster. They range in diameter from about 10 to 150 feet and are nearly circular, although the largest is elliptical and about 50 feet wide and 150 feet long. Relations between the pipes, the surrounding Mancos Shale, and the base of the laccolith are well exposed in draws leading northwest along the northern flank of the laccolith in the NE¼ sec. 31, T. 35 N., R. 18 W. The regional dip of the Mancos Shale in and around the northern flank of the laccolith is about 4° W., but near the pipes the shale dips 18° to 30° NE. (pl. 1).

The individual pipes consist of Mancos Shale and diorite porphyry in brecciated blocks and fragments cemented with travertine. The shale is principally in the outer parts of the pipes. It is so altered and hardened that it resembles mudstone, and is light gray green to pale brown, in contrast with the dark-gray to black fissile shale surrounding the pipes. The brecciated diorite porphyry is principally in the central parts of the pipes. In places, the porphyry fragments have been argillized, but most of them show no alteration effects other than the cementation by travertine.

The Mancos Shale below the laccolith is brecciated into fragments that average only a few inches in diameter, and the diorite porphyry for several feet above the base of the laccolith is broken into angular fragments

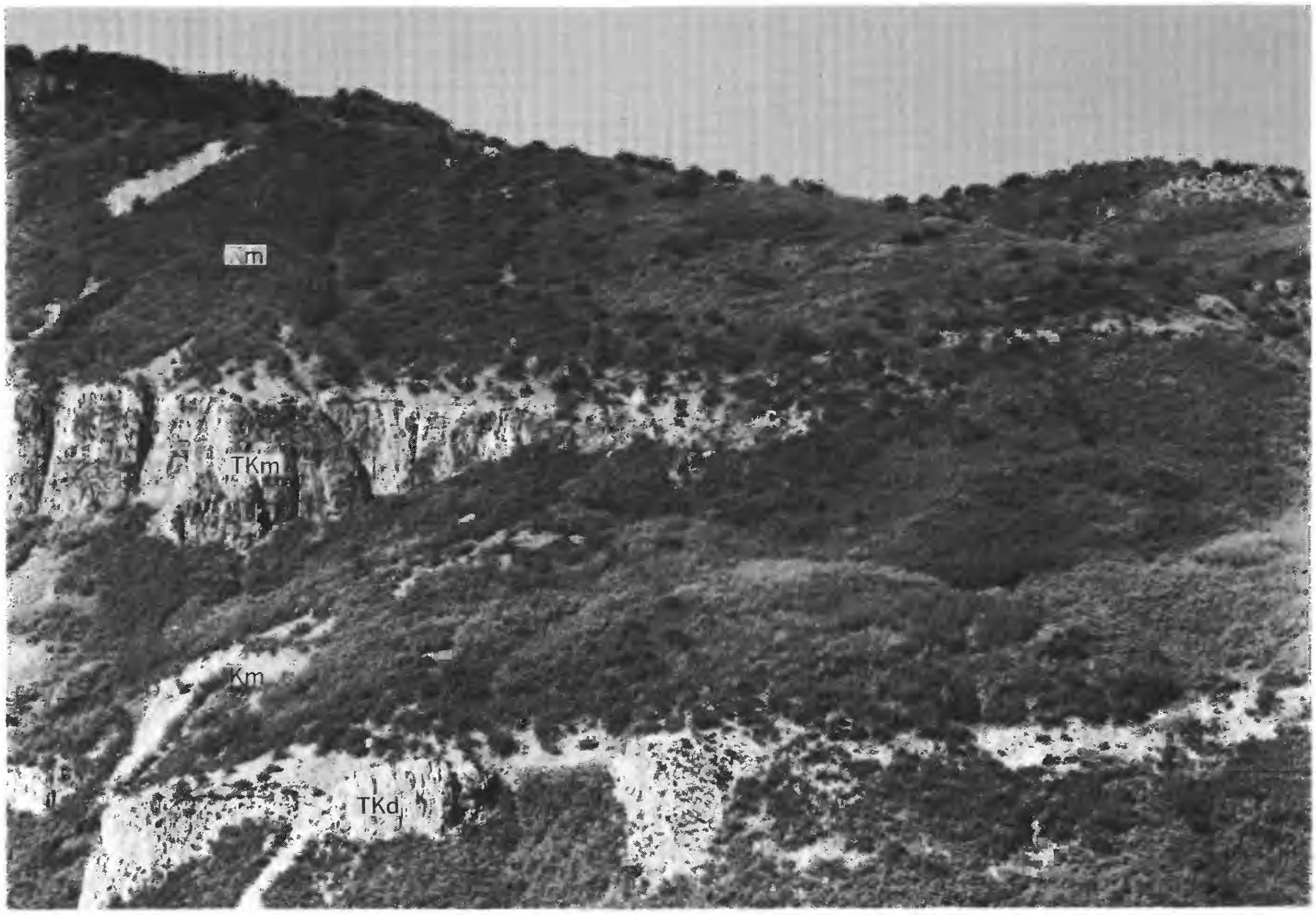


FIGURE 19.—Two sills in Mancos Shale (Km) along Pine Creek, north of Black Mountain. Upper sill is microgabbro (TKm) about 200 feet thick; lower sill is diorite porphyry (TKd). Viewed from the east.

that range from a few inches to several feet in diameter. Both the brecciated shale and porphyry are cemented with travertine for a distance of about 15 feet from the contact.

A sill of lamprophyre crops out in a draw south of the locality described above, in sec. 6 of unsurveyed T. 34 N., R. 18 W. Although no travertine-bearing pipes are exposed in the immediate vicinity of the sill, the sill is fractured, brecciated, and cemented with travertine. Figure 20 shows a boulder of brecciated lamprophyre that has slumped from the sill. The boulder is composed entirely of angular fragments of lamprophyre in a matrix of travertine. Figure 21 is a photograph of the sill. Some of the fractures are open and only partly filled with travertine. The solutions carrying calcium carbonate evidently moved laterally rather than vertically along the fractures in the sill, for the shale beneath the sill is "tight" and unfractured.

The pipes were probably formed by the explosive release of steam and hot water. The brecciation and fracturing of the sill and the basal part of the laccolith may have been caused by faulting and quaking prior to the hydrothermal activity, but the possibility exists that this brecciation was also due to the explosive action of water which gave rise to the breccia pipes themselves. The open nature of many of the fractures and the occurrence of travertine suggest that the fracturing took place when the rocks were at shallow depth or were exposed at the surface. The fracturing and hydrothermal (hot-spring) activity are therefore believed to be much later than the igneous activity that gave rise to the Ute Mountains.

SUMMARY OF GEOLOGIC EVENTS

The structural and stratigraphic history of the Ute Mountains area is an integral part of the geologic history of the Colorado Plateau. Cater (1955) has outlined the structural history of the area of salt anticlines on the plateau north of the Ute Mountains, and Strobell (1956) has summarized the geologic history of the Carrizo Mountains area, located approximately 25 miles south of the Ute Mountains. The important geologic

FIGURE 20.—Boulder of brecciated lamprophyre cemented with travertine.

FIGURE 21.—Fractured and brecciated sill of lamprophyre. Some of the fractures are open and only partly filled with travertine.

events as recorded by the rocks exposed in the Ute Mountains area are:

1. Predominantly subaerial deposition of the Navajo Sandstone from sources to the west in Late Triassic(?) and Jurassic time.
2. Deposition of the Entrada Sandstone under alternating subaqueous and subaerial conditions.
3. Deposition of the marine Summerville Formation.
4. Deposition of the Junction Creek Sandstone, partly subaqueous and partly subaerial.
5. Deposition of the Morrison Formation, partly fluvial and partly flood plain.
6. Deposition of coarse fluvial clastics of the Burro Canyon Formation of Early Cretaceous age from sources west or southwest of the Ute Mountains area.
7. Pronounced uplift and widespread erosion south of the Ute Mountains area.
8. Deposition of fluvial, swamp, and littoral rocks of the Dakota Sandstone during Late Cretaceous time.
9. Marine invasion and deposition of the Mancos Shale of Late Cretaceous age.
10. Deposition of marine sandstone and shale of the Point Lookout Sandstone in an oscillating Late Cretaceous sea.

The events that followed the deposition of the Point Lookout Sandstone in the Ute Mountains area and the age of the igneous rocks of the mountains can be inferred only from rocks exposed southeast of the Ute Mountains.

11. Deposition of the marine and continental shale and sandstone of pre-Animas, post-Point Lookout age (Menefee Formation, Cliff House Sandstone, Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, and Kirtland Shale).
12. Intrusion of igneous rocks:
    a. Microgabbro.
    b. Diorite porphyry.
    c. Granodiorite porphyry.
    d. Quartz monzonite porphyry.
13. Erosion in the Ute and La Plata Mountains and deposition of coarse clastics (in the McDermott Member of the Animas Formation of Late Cretaceous age) to the south and east.

ECONOMIC GEOLOGY

METALLIC MINERAL DEPOSITS

Small deposits of uranium, vanadium, and copper along the northern edge of the Ute Mountains and in the vicinity of McElmo Canyon have been extensively prospected, but thus far have not proved to be of much commercial value. Except for the generally barren iron-stained pyritic alteration zones in some of the intrusive bodies, no metallic mineral deposits are known in the Ute Mountains proper.

The uranium deposits include (a) fault-controlled deposits that contain abundant pyrite and sparse copper minerals, and (b) flat-lying deposits containing vanadium minerals in beds at considerable distances from known faults. The copper deposits are all associated with faults or shear zones.

Commercial deposits of uranium and vanadium occur in the Salt Wash Member of the Morrison Formation in Montezuma Canyon, Utah, about 10 miles northwest of the northwest corner of the Moqui SW quadrangle, and in the Carrizo Mountains of Arizona, about 25 miles southwest of the Ute Mountains. Very large deposits of uranium and vanadium occur in the Jackpile sandstone (of local usage) in the Morrison Formation far south of the Ute Mountains in the vicinity of Grants, N. Mex. Because of the widespread occurrence of uranium deposits in the Salt Wash Member on the Colorado Plateau, the Salt Wash was considered to have the greatest potential in the Ute Mountains area and was studied in considerable detail during the present work.

URANIUM DEPOSITS

FAULT-CONTROLLED DEPOSITS

CLIFF HOUSE GROUP OF CLAIMS

The Cliff House group of claims lies in secs. 22, 23, and 27, T. 36 N., R. 18 W. All the prospects in this group are about 1½ miles north of McElmo Creek (fig. 22) and can be reached by an access road, built by the Atomic Energy Commission, that leaves Colorado Highway 32 just north of Battle Rock. The Cliff House group was owned in 1957 by the Four Corners Uranium Co., Denver, Colo.

Cliff House prospect.—The Cliff House prospect (fig. 22) is along a northeast-trending fault along which beds of the Summerville Formation are displaced 180 feet down to the northwest and brought against the upper part of the Navajo Sandstone (fig. 23). The radioactive area is about 100 feet long and is limited to a zone where mudstone and sandstone of the Summerville

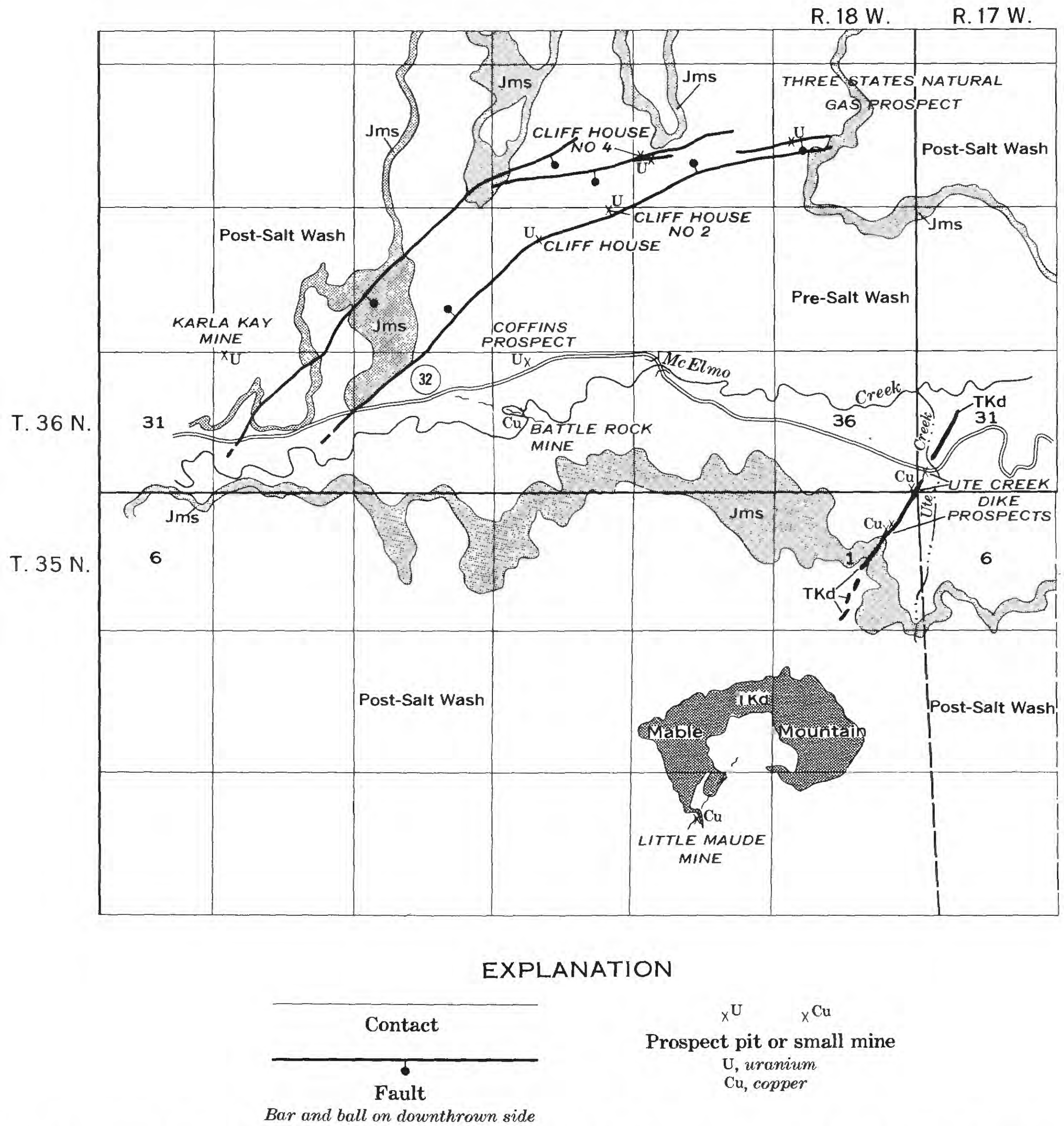


FIGURE 22.—Map showing location of mines and prospects. TKd, diorite porphyry; Jms, Salt Wash Member of the Morrison Formation (stippled).

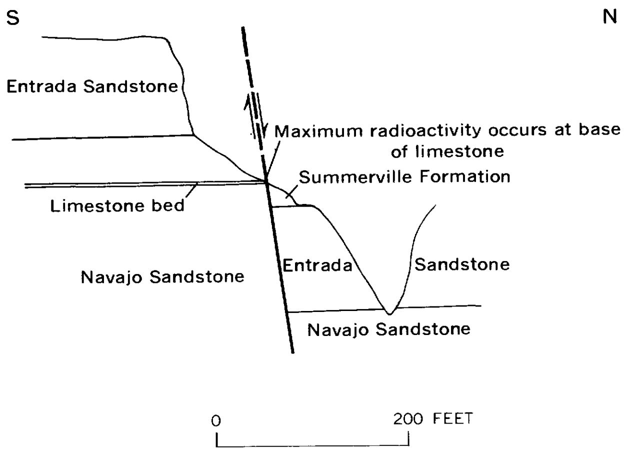


Figure 23.—Sketch showing stratigraphic and structural relations at the Cliff House prospect, McElmo Canyon, Montezuma County, Colo.

Formation are in contact with a limestone bed about 4 feet thick in the Navajo Sandstone. Rocks in the prospect area are intensely stained with limonite, and much carbonate has been leached from the limestone bed. Scintillation-counter measurements indicate that most of the radioactive material is concentrated in sandstone at the base of the leached limestone. No minerals of uranium or vanadium were identified. Sample 55–E–12 (table 13), chipped from sandstone in contact with the leached limestone, assayed 0.038 percent eU_3O_8, 0.040 percent U_3O_8, and 0.16 percent V_2O_5.

A radiometric survey was made of the fault line for several hundred yards east and west of the prospect area; no radioactivity above background was noted.

Cliff House No. 2 prospect.—The Cliff House No. 2 prospect is about half a mile northeast of the Cliff House prospect (fig. 22) along the same northeast-trending fault. In the Cliff House No. 2 area, downward displacement on the northwest side of the fault is only about 100 feet, and the Entrada Sandstone is in contact with uppermost beds of the Summerville. Radioactivity is only slightly above background. The sandstone in the Summerville is strongly stained yellow-brown by limonite near the prospect, but farther away the sandstone changes gradually to the pink color characteristic of this stratum in the McElmo Canyon area. The sandstone is probably the same bed that is radioactive in the Cliff House No. 4 prospect.

Cliff House No. 4 prospect.—The Cliff House No. 4 workings consist of two very short drifts and several small pits dug into or near two east-trending faults (fig. 24). The northern fault has about 80 feet of displacement with the south side down. The beds are displaced 15 feet down on the north side of the southern fault; consequently there is a small graben in the prospect area. The southern fault dips about 80° to the north and probably intercepts the northern fault at depth (section *A–A′*, fig. 24). The highest radioactivity occurs near the southern fault; a chip sample (55–E–10, table 13) taken in this zone assayed 0.053 percent eU_3O_8, 0.028 percent U_3O_8, and less than 0.1 percent V_2O_5. The radioactive material has not been identified; it is closely associated with limonite, hematite, barite, asphaltite, and sparse copper carbonates concentrated in a flat-lying upper sandstone bed of the Summerville and in fault breccia adjacent to this bed. The radioactivity diminishes southward from the faulted area and, in general, where it diminishes the content of limonite decreases. The upper bed of the Summerville between the faults, and north of the north fault, is not radioactive. In holes drilled by the U.S. Atomic Energy Commission (AEC) along the north and south faults and in the intervening graben there is no increase of radioactivity at depth. Pyrite and marcasite were identified in the AEC drill cores by Coleman and Delevaux (1957, p. 513).

THREE STATES NATURAL GAS CO. PROSPECT

Uranium prospects in sec. 24, T. 36 N., R. 18 W., are on an oil and gas lease owned by the Three States Natural Gas Co. and on a mineral claim located by Ben Archibeque, Mancos, Colo. The area is about 200

Table 13.—*Radiometric and chemical analyses, in percent, of samples from radioactive prospects, McElmo Canyon, Montezuma County Colo.*

[Analysts, 1, D. L. Schafer, H. H. Lipp, J. E. Wilson; 2, C. G. Angelo; 3, C. G. Angelo, J. P. Schuch, J. E. Wilson]

Sample No.		Analysts	Prospect or mine sampled		Radiometric analysis	Chemical analysis	
Field	Laboratory		Name	Material	Equivalent uranium (eU_3O_8)	Uranium (U_3O_8)	Vanadium pentoxide
55–E–5	229457	1	Three States Natural Gas Co	Sandstone	0.049	0.015	<0.1
55–E–6	229458	1	do	do	.028	.019	<.1
55–E–7	229459	1	do	do	.021	.006	<.1
55–E–8	229460	1	Coffin's	do	.004	----------	.52
55–E–9	229461	1	do	do	.008	----------	.93
55–E–10	229462	1	Cliff House No. 4	Limonitic sandstone	.053	.028	<.1
55–E–12	229464	1	Cliff House	do	.038	.040	.16
55–E–26B	238257	2	do	Leached limestone	.002	----------	----------
55–E–20	238266	3	Karla Kay	Green mudstone, Brushy Basin Member	<.001	----------	----------
55–E–21	238267	3	do	Sandstone from Karla Kay Conglomerate Member	.004	----------	----------
55–E–22	238268	3	do	Mudstone pebble conglomerate, Karla Kay Conglomerate Member.	.016	.019	.32
55–E–24A	238269	3	do	Karla Kay Conglomerate Member	.007	.012	<.1

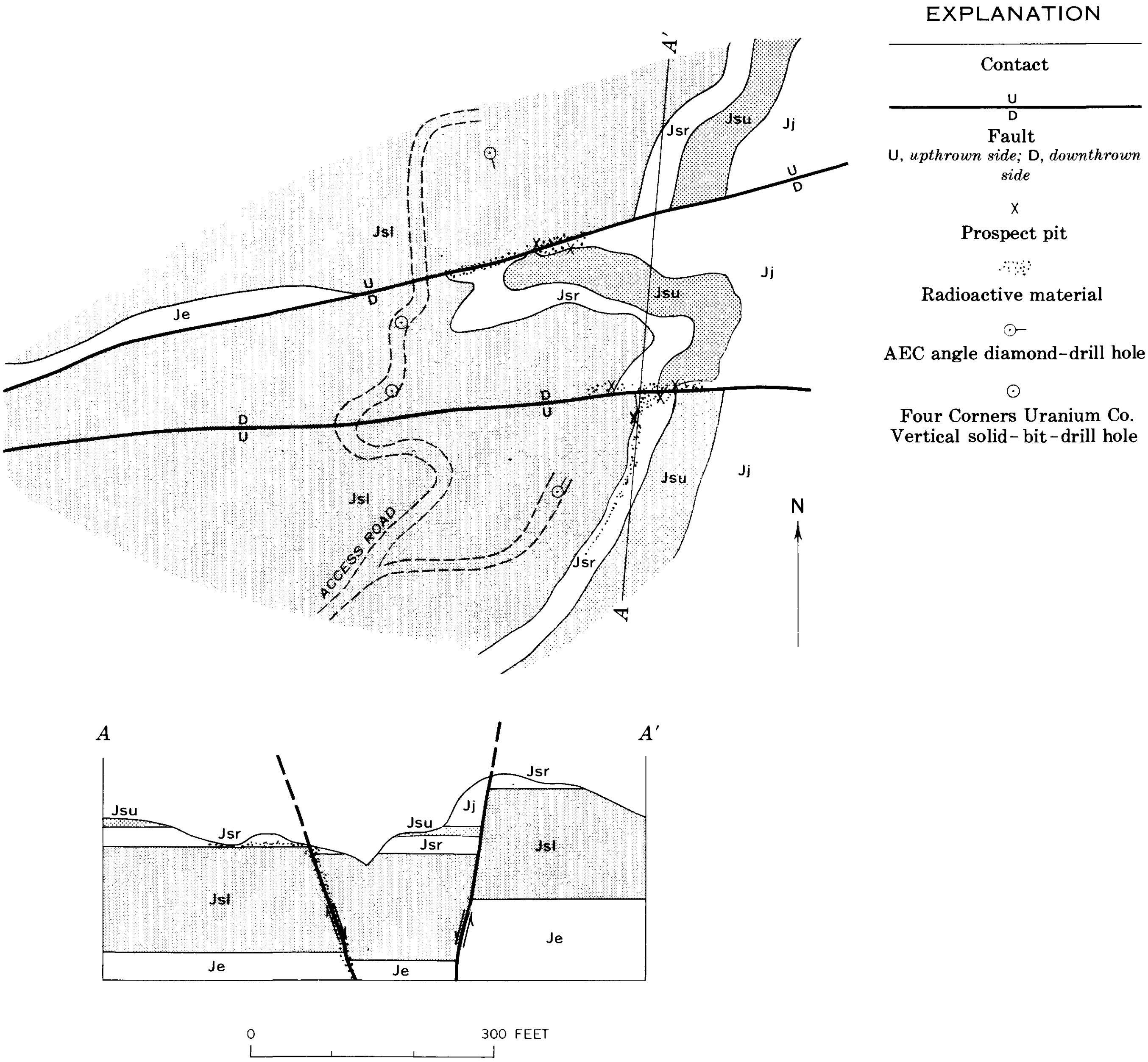


Figure 24.—Cliff House No. 4 area, McElmo Canyon, Montezuma County, Colo. Jj, Junction Creek Sandstone: Jsu, upper part, Jsr, radioactive sandstone bed, and Jsl, lower part, all of the Summerville Formation, and Je, Entrada Sandstone.

feet south of the Schmidt 1 carbon dioxide well and can be reached by a 2-mile access road from Colorado Highway 32.

Two prospect pits about 60 feet apart are dug into the Entrada Sandstone along a northeast-trending fault that displaced beds of the Summerville Formation 10 feet down to the southeast, against the Entrada Sandstone. The highest radioactivity is in the east pit, which is dug into sandstone on the north side of the fault. Of three samples taken in this pit during the present work, the most radioactive (sample 55–E–5, table 13) assayed 0.049 percent eU_3O_8, 0.015 percent U_3O_8, and no V_2O_5.

Veinlets of asphaltic material were noted in fault breccia in the prospect area. The asphaltic material has been "dried"; it is black, has a pitchy luster, is brittle, and can be ground to a brown powder between the fingers.

BEDDED URANIUM DEPOSITS

KARLA KAY MINE

The Karla Kay mine is near the NW cor. sec. 32, T. 36 N., R. 18 W. The mine area is claimed by the Four Corners Uranium Co. and can be reached by a 1½-mile access road that leaves Colorado Highway 32 at the house site of the Fowler Farm in McElmo Canyon.

The mine has 70 feet of workings divided among three drifts to the north, east, and south (fig. 25). The mine was started in radioactive talus and the workings entered coarse clastic rocks of the lowermost part of the Burro Canyon Formation.

Three sets of joints break the rocks in the mine—one set strikes consistently northeast, another northwest, and a poorly defined third set, about east. The ground is badly broken by these fractures and by collapse due to removal by underground water of mudstone beneath the sandstone of the Burro Canyon.

Most of the radioactive material in and around the mine is in a lentil of mudstone conglomerate (fig. 26) that is part of the Karla Kay Conglomerate Member (Ekren and Houser, 1959a) of the Burro Canyon Formation. The conglomerate contains pebbles and slabs of green mudstone in a matrix of coarse conglomeratic and cherty yellow-brown sandstone. It contains abundant tree molds, but few carbonized tree remnants. The conglomerate lentil occupies a channel cut in bentonitic mudstone of the Brushy Basin Member of the Morrison Formation and underlies a fine- to medium-grained, poorly sorted quartz sandstone that contains very sparse pebbles of variegated chert. This sandstone bed underlies the main lens of the system of shoestring conglomerates of the Karla Kay. Both the mudstone conglomerate and the overlying coarse sandstone were eroded prior to the deposition of the main lens of the Karla Kay east and west of the mine.

The highest radioactivity is associated with carbonized plant debris in the back of the north drift at the top of the mudstone conglomerate lentil (fig. 25). This material is estimated to have about 0.05 percent U_3O_8. Carnotite is weakly disseminated in the conglomerate and forms a coating on pebbles of mudstone. Radioactivity is not concentrated along any of the fractures in the mine, many of which contain gypsum, limonite, and dendrites of pyrolusite. Radiometric traversing to the east, north, and west of the mine did not disclose significant radioactivity.

The radioactive material in the Karla Kay mine has not proved to be of commercial value (table 13), and no ore has been shipped from the mine. Several small deposits of uranium have been found associated with the shoestring conglomerates of the Karla Kay west of

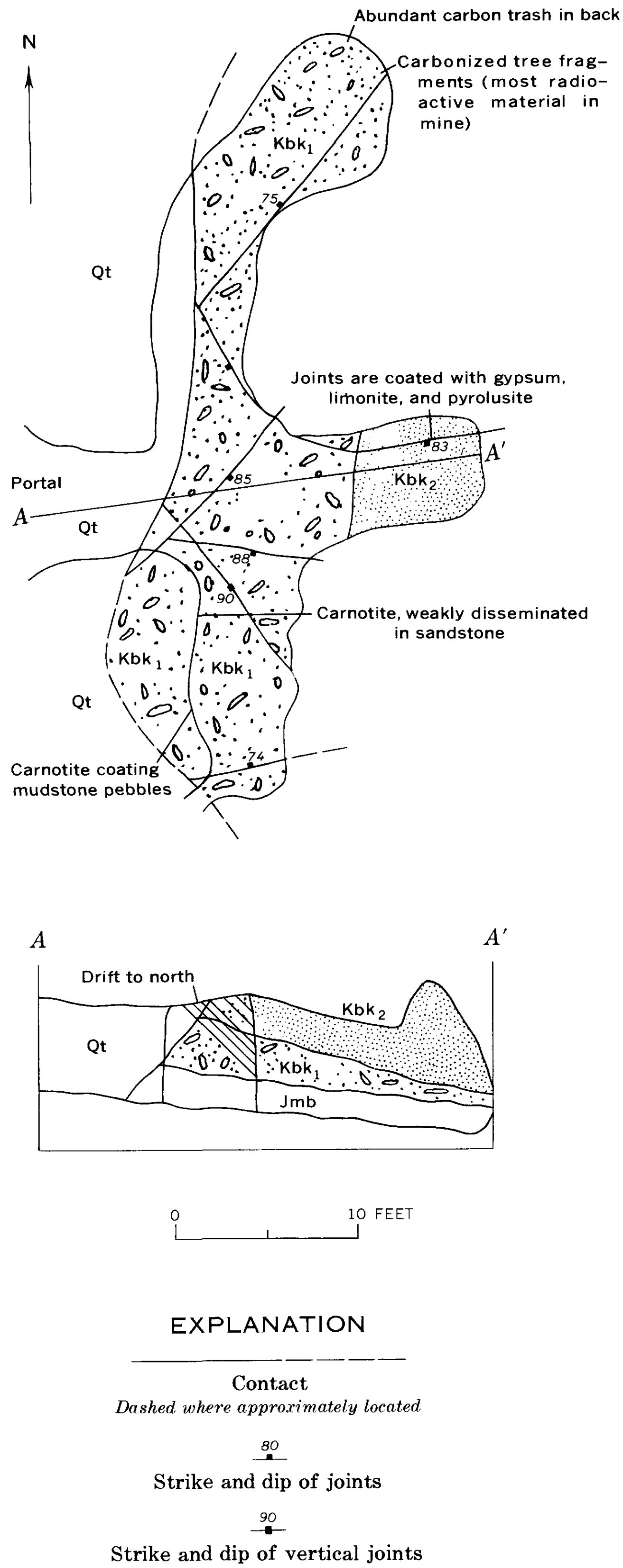


FIGURE 25.—Map and section of the Karla Kay mine, McElmo Canyon, Montezuma County, Colo. Qt, Quaternary talus deposits; Kbk_2, sandstone, and Kbk_1, mudstone, of Karla Kay Conglomerate Member of the Burro Canyon Formation; Jmb, mudstone of Brushy Basin Shale Member of the Morrison Formation. Level of plan view is waist height.

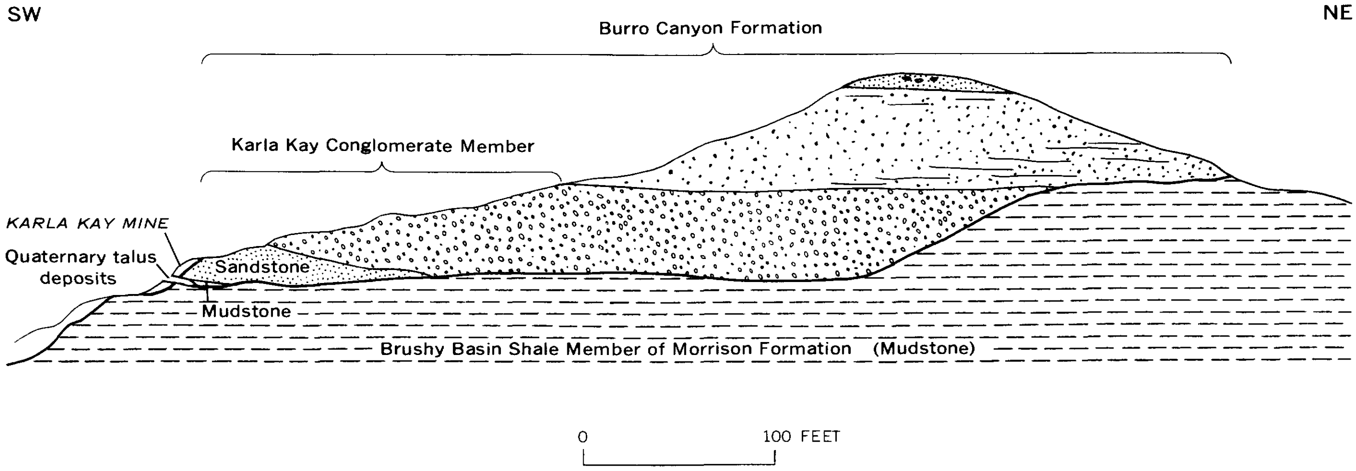


FIGURE 26.—Sketch showing stratigraphic relations at the Karla Kay mine. Collapsed beds have been restored to horizontal position.

the Ute Mountains area, however, and some of this material has been mined.

COFFIN'S PROSPECT

Coffin's prospect is on the John Meadows Ranch a few feet north of Colorado Highway 32, in sec. 34, T. 36 N., R. 18 W. This prospect was described by Coffin (1921).

The mineralized material is in flat-bedded sandstone near the middle of the Entrada Sandstone. The prospect was opened in 1913 and the pit has since been filled with alluvium and windblown silt. The mineralized rock is exposed in an outcrop about 130 feet long by 40 feet wide that extends south under the highway. It is eroded away north and east of this exposure and is covered by alluvium to the south and west. Holes dug for fenceposts and power poles along the road show the mineralized zone to be about 6 inches thick. The vanadium-uranium minerals and traces of malachite are concentrated along bedding planes and do not seem to be influenced or controlled by fractures. A 1-inch seam within the mineralized zone is richer than the rest and contains a dark-gray mineral, probably vanadium mica. The secondary minerals pintadoite and carnotite occur as coatings on fresh fractures.

No ore has been shipped from this prospect. Assays of chip samples taken along the most intensely mineralized seam during the present study are shown in table 13. A sample taken by Coffin (1921) assayed more than 1.0 percent V_2O_5 and 0.09 percent U_3O_8. The deposit at the prospect differs from others in the Ute Mountains area in that vanadium is much more abundant than uranium. The assays in table 13 indicate approximately a 100 : 1 ratio, and the assay reported by Coffin shows a 10 : 1 ratio.

COPPER DEPOSITS

BATTLE ROCK MINE

The Battle Rock workings are in a mineralized shear zone that extends the full length of Battle Rock, a natural monolith in McElmo Canyon in sec. 34, T. 36 N., R. 18 W. The shear zone trends N. 75° W. and is from 10 to 15 feet wide. The introduction of silica, barite, limonite, and carbonates along the shear zone indurated the normally friable Junction Creek Sandstone and altered its color from reddish orange to brown. The indurated rock in and adjacent to the shear zone weathers in relief, and thus forms the monolith.

The workings are only partly accessible; only the main drift was examined. Sparse copper carbonates in a barite gangue, and abundant limonite or hematite, or both, were found there. Rock on the mine dump has sparse chalcopyrite. No ore has been shipped from the mine.

UTE CREEK DIKE PROSPECTS

Several prospect pits have been dug into baked sedimentary rocks and sheared diorite porphyry along the sides of the Ute Creek dike (fig. 22). Most of these pits are devoid of visible ore materials, although a few show sparse copper minerals distributed along fractures. A shallow shaft that exposes copper minerals in sheared diorite was studied by E. M. Shoemaker and W. L. Newman, who reported (written commun., 1953) that: "The sheared diorite is intensely kaolinized locally. Copper minerals, chiefly malachite, azurite, and copper pitch are distributed along fractures, in small cavities, and replace altered feldspar and hornblende phenocrysts."

LITTLE MAUDE MINE

The Little Maude mine, in sec. 14, T. 35 N., R. 18 W. (fig. 22), is a single drift approximately 50 feet long in baked and sheared limy mudstone of the Mancos Shale. The back of the drift is the base of a thin sill that is the featheredge of the Mable Mountain bysmalith. The drift follows a shear zone that contains much pyrite and seems to be part of the fracture system along which the Ute Creek dike was intruded.

RELATION OF THE METALLIC MINERAL DEPOSITS TO THE IGNEOUS ROCKS

The occurrence of uranium and other metals in faults in the Ute Mountains area is of geologic interest because of the controversy regarding the origin of the uranium deposits on the Colorado Plateau. The fundamental questions regarding the uranium in the McElmo Canyon area are these: Were the uranium and associated metals derived from hypogene solutions? If so, were the solutions related to the igneous rocks of the Ute Mountains?

The field data indicate that the copper deposits of Battle Rock and the Ute Creek dike were almost certainly derived from hydrothermal solutions related to the igneous activity of the Ute Mountains. These deposits occur in sheared or faulted zones that are radial to the intrusive bodies (pl. 1) and, specifically, to the Mable Mountain bysmalith that probably overlies a fracture zone.

A large part of the Mable Mountain intrusive body has been pyritized and altered. Intensely altered areas partly surrounded by vein deposits of metallic minerals (especially base metals) are a well-known feature of mineral districts of hydrothermal origin in southwestern Colorado. The pyritization at Mable Mountain was probably hydrothermal and related to the introduction of copper minerals in the veinlike deposits of Battle Rock and along the Ute Creek dike.

The introduction of uranium and sparse copper in the faults of the Cliff House No. 4 and Three States Natural Gas Co. prospects probably was accomplished during the same hydrothermal stage as the pyritization at Mable Mountain. The abundance of pyrite and marcasite at depth in the Cliff House No. 4 veins and the occurrence of asphaltite in both this prospect and that of the Three States Natural Gas Co. indicate that the introduced material in the arcuate faults was largely derived from ascending solutions. The asphaltite probably came from petroliferous beds that underlie the uranium deposits, because, in the McElmo Canyon area, petroleum is unknown in rocks younger than those that carry the deposits.

The ubiquity of barite in fractures along McElmo Canyon is significant because the igneous rocks of the Ute Mountains are abnormally rich in barium. (See table 4.)

Fourteen samples from the fault-controlled and the bedded mineral deposits were analyzed spectrographically in an attempt to find clues that might indicate a source for the metals (table 14). Analyses of barren rock from the formations that contain these deposits are also shown in the table for comparative purposes. The spectrographic data indicate that iron, barium, cobalt, chromium, copper, molybdenum, nickel, lead, strontium, vanadium, yttrium, and ytterbium occur in greater than background quantities in both the fault-controlled and the bedded deposits. On the other hand, silver, arsenic, antimony, niobium, zinc, and manganese occur in greater than background values only in the fault-controlled deposits. All the elements listed above, with the exception of silver, antimony, and niobium, also occur in greater than background values in the nonradioactive copper deposits in Battle Rock.

Vanadium is found only in one fault-controlled radioactive deposit, the Cliff House prospect. Mineralized limestone in the Navajo Sandstone at this prospect contains about 300 ppm of vanadium (sample EMS–9–53, table 14), and limonitic sandstone contains 900 ppm of vanadium (sample 55–E–12, table 13), more than 50 times the background for Navajo Sandstone. The vanadium may be related to dried asphaltic material that is common as veinlets in the fractures of this vicinity.

It is concluded that most of the metals, including uranium, were introduced into the fault-controlled deposits by ascending (hypogene) solutions related to the igneous activity in the Ute Mountains. The minor elements of the bedded uranium deposits are similar to those in the fault-controlled deposits and they may therefore be of the same origin. It is unlikely, however, that the Ute magmas were the source of uranium and other metals in the large bedded deposits in the Morrison Formation of nearby areas in southwestern Colorado, because the hydrothermal activity associated with the igneous intrusions of the Ute Mountains was feeble and therefore probably not capable of supplying the necessary volume of metals. In contrast with the stocks of the Henry Mountains (Hunt and others, 1953, p. 217–220) and the Abajo Mountains (I. J. Witkind, oral commun., 1957), the stocks of the Ute Mountains are unmineralized.

URANIUM POTENTIAL OF THE UTE MOUNTAINS AREA

NORTHERN UTE MOUNTAINS AREA

The uranium potential of the area that includes the northern fringes of the mountains and McElmo Canyon is believed to be extremely small. The known deposits, described above, have thus far proved to be too poor to be of commercial value. Intense prospecting in this area of dissected and well-exposed beds of the Morrison Formation between 1950 and 1958 failed to disclose commercial deposits. Nevertheless, because the lower members of the Morrison Formation contain uranium deposits in adjacent areas, they were studied in considerable detail during geologic mapping.

The Westwater Canyon Member of the Morrison Formation averages less than 100 feet in thickness in McElmo Canyon. The Salt Wash Member averages about 200 feet in thickness in the eastern part of the canyon, where the Recapture Member is absent, but it thins westward to about 100 feet where the Recapture Member is present. Throughout McElmo Canyon the Salt Wash consists of continuous lenses or rims of sandstone separated by lenses of reddish-brown mudstone. In some areas, there are four or more distinct lenses of mudstone, but in others mudstone is in extremely thin units and the Salt Wash forms a single thick sandstone unit. Very little green or altered mudstone is present below or above the individual lenses of sandstone and, where present, the altered mudstone extends for only a few tens of feet and is only a few inches thick. Pebbles and seams of mudstone within the sandstone lenses, however, are commonly green. No accumulations of "carbonaceous trash" are known, but fine particles of carbon are fairly abundant along bedding planes.

The lack of extensive greenish or altered mudstone, the absence of "carbonaceous trash", and the nonlenticular character of the sandstone of the Salt Wash in this area as compared to uranium-producing districts suggest that the area is generally unfavorable for uranium deposits (Weir, 1952). The environment in which the sandstone beds were deposited apparently did not permit large accumulations of carbon, nor the development of zones of contrasting transmissivity.

SOUTHERN UTE MOUNTAINS AREA

The lower beds of the Morrison are exposed in only one place in the southern Ute Mountains area. This exposure is approximately a quarter of a mile south of the "East Toe" or Sentinel Peak. Here, approximately 250 feet of the Westwater Canyon Sandstone Member overlies 250 feet of the Recapture Shale Member of the Morrison Formation. The Salt Wash Sandstone Member either is absent or is in a mudstone facies mapped as Recapture Member.

The abrupt change in lithology of the lower beds of the Morrison may be a favorable feature. The rich uranium deposits of the Uravan district, Montrose County, Colo., are localized in sandstone that pinches out completely or thins abruptly within short distances from productive areas (Boardman and others, 1956). It seems quite certain that zones of contrasting transmissivity (Jobin, 1962) within the beds of the Salt Wash exist between the southern Ute Mountains area and McElmo Canyon. Uranium deposits may occur in or near these zones. The most economical area to explore for such deposits is the western flank of the Ute dome. Many drilling sites are readily accessible in the canyons and on the tops of mesas and pediments lying west of the igneous terrane. The approximate depth to the base of the Salt Wash in such places ranges from 400 feet in areas where the Brushy Basin Member of the Morrison is at the surface to 800 feet where the top of the Dakota is at the surface. Although the Morrison Formation is present beneath many of the igneous bodies, exploration beneath these bodies would be expensive because of the depth of drilling and the structure and hardness of the rock.

Criteria for recognizing favorable ground in areas containing the Westwater Canyon Sandstone Member have never been completely outlined. Thaden and Santos (1956) reported that ore has not been found in the Westwater Canyon Member where the sandstone is split into many tongues or where it is less than about 100 feet thick. The Westwater Canyon is thicker than 100 feet in the southern part of the Ute Mountains area, but the possibility of its being a host for large deposits is probably remote inasmuch as no deposits have been found in this member where it is widely exposed in adjacent areas of Utah, Arizona, and northwestern New Mexico.

NONMETALLIC MINERAL DEPOSITS

PETROLEUM, NATURAL GAS, AND CARBON DIOXIDE

KNOWN OCCURRENCES

Only minor amounts of oil and gas had been produced from the Ute Mountains area before 1958, and this production was confined to McElmo dome. The structure and oil and gas possibilities of McElmo dome have been summarized by Zabel (1955), who stated that of six wells drilled on or near the crest of the dome, only one, the MacIntosh 1 (pl. 1), produced hydrocarbons. Initial potential of the well was 500,000 cu ft flammable gas per day. The gas from this well is used as fuel by a dry-ice plant of the Colorado Carbonics Co. in McElmo Canyon. Two other wells also supply this plant with carbon dioxide gas. The A. H. Schmidt 1 yields carbon dioxide from the Leadville limestone and had an initial potential of 20,000 Mcf (thousand cubic feet) gas per day. The Dudley 1 yields from the same rocks and had an initial potential of 7,000 Mcf gas per day.

The Fulks 1 well, drilled in the NW¼ sec. 27, T. 37 N., R. 17 W. (not in the mapped area), yielded some carbon dioxide from the Mississippian and Lower Cambrian rocks. Granite was reached at a depth of 8,637 feet, and the hole was abandoned at 8,787 feet.

The West 1 well (pl. 1) found strong shows of oil in the upper part of the Hermosa Formation at an approximate depth of 3,300 feet.

OIL AND GAS POSSIBILITIES OF THE UTE MOUNTAINS AREA

The oil and gas possibilities of the Ute Mountains area have recently been enhanced by the discovery of several major oil fields in southeastern Utah, the largest of which is the spectacular Aneth field. Production in these fields is from two zones in the Hermosa Formation—designated the Desert Creek and the Bluff zones by Herman and Barkell (1957). The reservoir at Aneth, Utah, is described as a carbonate buildup in the Desert Creek zone and is considered by some geologists to be a reef. The reef apparently has a northwest trend that parallels the southwest flank of the Paradox structural basin.

UTE DOME

The possibility has been discussed by Hunt (1942) that the domes formed by laccolithic mountains may be oil bearing. Hunt pointed out that oil geologists have had little interest in laccolithic mountains because the laccoliths have been generally interpreted as mushroom-shaped bodies overlying undisturbed strata. The knowledge that laccoliths were injected laterally from stocks that occupy the centers of structural domes greatly enhances the oil and gas possibilities.

Hunt's (1942) conclusions are believed to be applicable to the Ute Mountains. The Ute dome could be an excellent structural trap, for it has large closure and contains formations that are productive in nearby areas.

The paucity of oil and flammable gas in McElmo dome and the abundance of carbon dioxide may be considered negative indications as to the possibilities of oil and gas in the Ute dome. The origin of the carbon dioxide gas in the McElmo structure is unknown. Carbon dioxide in other areas is thought to have originated from the metamorphism of hydrocarbons by contact with hot mineralized waters, or from the metamorphic action of magmas and hot solutions intruding limestone (Dobbin, 1935, p. 1068–1069). Whatever the origin, the carbon dioxide in the McElmo dome apparently is related to igneous activity either directly below McElmo dome or in the Ute Mountains, and it seems probable that carbon dioxide will also be found in carbonate-bearing rocks in parts of the Ute dome. Whether this gas, if it exists at all, completely fills the potential reservoir rocks in the structure can be determined only by drilling.

COAL

The Dakota Sandstone in the Ute Mountains area contains abundant thin beds of coal, but with few exceptions these beds are extremely lenticular and have little commercial value. One bed with reportedly large reserves is exposed a few miles east of Cortez, Colo.

M. A. Pishel (written commun., 1911) studied the coals in the Dakota of southwestern Colorado and stated, "The coal is low-grade bituminous in character, containing relatively large amounts of finely disseminated siliceous matter which in the analysis shows up as ash." One of the several samples of coal from the Dakota that Pishel had analyzed was from the McElmo Canyon area. This analysis follows.

Analysis of coal sample from the Dakota Sandstone, SE¼ sec. 3, T. 35 N., R. 18 W., McElmo Canyon area

[Analyst unknown, sample fairly fresh]

Loss of moisture on air-drying	percent	3.20
Analysis of air-dried sample:		
Moisture	do	4.69
Volatile matter	do	21.68
Fixed carbon	do	60.62
Ash	do	13.00
Sulfur	do	.48
Calories		6,232
Btu		11,218

Coal beds more than 2 feet thick were observed in several exposures during the geologic mapping, principally in the Moqui SW quadrangle in T. 35 N., Rs. 18 and 19 W. Local ranchers have mined small amounts of the coal in this area for use as fuel. A coal bed approximately 8 feet thick was observed in the Sentinel Peak NE. quadrangle, about half a mile south of Sentinel Peak. This bed consists of a lower seam of good coal about 4 feet thick, impure coal about 1 foot thick, and two upper 1-foot seams separated by impure coal and carbonaceous shale. The exposure is limited and the extent of the bed could not be determined.

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