T-901

THE GEOLOGY OF THE DEVILS HEAD QUADRANGLE, DOUGLAS COUNTY, COLORADO

By

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ABSTRACT

The Devils Head quadrangle, in western Douglas County, Colorado, is on the boundary between the Great Plains and the Southern Rocky Mountains physiographic provinces. From the level plains on the east, the land rises sharply to mountains that represent a dissected peneplain.

Sedimentary rocks, occurring only along the east edge of the quadrangle, consist of sandstones, siltstones, shales and conglomerates, with a little limestone and gypsum, and range in age from Late Cambrian to Early Tertiary.

Precambrian metamorphic rocks, metamorphosed sediments of the Idaho Springs formation, consist mostly of high-grade gneisses and schists of the almandine amphibolite metamorphic facies. Along the contact with Pikes Peak granite, some gneisses of the pyroxene hornfels facies occur.

The quadrangle includes the northeast corner of the Pikes Peak batholith, and most of the area is underlain by pink coarse-grained granite, leucogranite, and quartz monzonite.

Compositional variation within this part of the batholith is not great, and the texture of rock is quite uniform.

The granite solidified about 1050 million years ago. Its magma may have formed by partial fusion of rocks that were deeply downfolded during a strong regional tectonism about 1500 million years ago. The granite apparently rose from depth and was emplaced by forcible intrusion, probably by uplift of its cover.

X-ray and chemical studies of feldspars from the granite indicate considerable unmixing of sodic plagioclase from the microcline of the granite; extensive recrystallization of the plagioclase occurred. The final temperature of unmixing was low and uniform throughout the area.

Many small aplites and pegmatites are in the granite, particularly near Devils Head itself. The aplites and pegmatites, mineralogically and chemically similar to the granite, probably formed as late-stage segregations.

The granite is intruded by a number of diabasic andesite dikes of probable Tertiary age that lie along two major north-trending fault zones. A continuous high magnetic anomaly along one of the fault zones indicates that the dikes may represent discontinuous higher projections of a dike that is continuous at depth. A positive gravity anomaly that underlies the region might be explained by a large mass of basic rock at depth.

The Devils Head quadrangle is in the transition zone between the Denver structural basin and the Front Range massif. Along the eastern edge of the quadrangle, the sedimentary rocks have been bent steeply to vertically upward in monoclinal folds, and the granite has been thrust over the sedimentary rocks along high-angle reverse faults. A series of vertical cross-faults transects this disturbed belt. Three major north-trending faults cut the area. Direction and amount of movement cannot be determined, except in one place where the contact between granite and metamorphic rocks has been offset left-laterally about half a mile. A prominent east-west and north-south joint system appears to be related to the faults.

Sandstone dikes occur in the north-trending fault zones and in shears associated with the thrust faults. The dikes were formed by downward injection of loose Sawatch sands into fissures opened in the granite by faulting.

In remote Precambrian time a thick series of marine sediments was deposited in the area. Regional tectonism 1500 million years ago was followed by intrusion of the Pikes Peak batholith 1050 million years ago, and subsequently by uplift, erosion, and peneplanation.

The Sawatch sandstone was deposited by a transgressing sea in Late Cambrian time and was subsequently eroded away over most of the area. Uplift of the Ancestral Rocky Mountains was followed by deposition of continental and near-shore marine sediments during Late Paleozoic and Early Mesozoic time. Late Mesozoic subsidence resulted in deposition of a thick series of clastic marine sediments that gradually gave way to terrestrial deposits as the land rose again.

Laramide deformation caused monoclinal folding and thrust faulting and was accompanied by igneous activity. Post-Laramide peneplanation followed by uplift and differential erosion has developed the present topography.

Although feldspar, stone, gem stones, and gypsum have been produced in the past, and there has been prospecting for gold, coal, petroleum, clay, sand, radioactive and rare earth minerals, lead and zinc, the economic mineral potential of the Devils Head quadrangle is low.

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ILLUSTRATIONS

INTRODUCTION

Purpose

This investigation was instituted to provide a better understanding of the geology of the Colorado Front Range. Specific objectives were preparation of a detailed map of the geology of the Devils Head quadrangle; determination of the geologic structure and history of the area; and an explanation of the petrology of the Pikes Peak granite, the major rock type in this area. The study was undertaken at the suggestion of Dr. Robert M. Hutchinson of the Department of Geology, Colorado School of Mines, who was beginning a regional study of the Pikes Peak batholith and related rocks.

Previous Work

Although a number of investigators have studied the Devils Head area no detailed work has been done except on the eastern edge of the area. Only generalized descriptions and small scale maps have been published. (Cf. Boardman, 1954).

The earliest studies, of reconnaissance nature, were by members of the Hayden surveys. (Peale, 1873; Hayden, 1877). The area is included in maps by Darton (1905), Spurr, Garrey, and Ball (1908), Campbell (1922), Lovering (1935), Brown (1943), and Lovering and Goddard (1950). These maps show the geology of surrounding areas but provide little or no specific information on the Devils Head quadrangle. The geologic map of Colorado (Burbank and others, 1935) shows the results of some of these workers.

Cannon (1891) published a brief account of the geology of Perry Park, and Lee (1902) discussed the areal geology of the Castle Rock region, including Perry Park. Kruger, Hamilton, and Enriquez (1910) discussed the geology of Perry Park but without a map. Richardson (1915) mapped the adjacent Castle Rock quadrangle in detail.

Several regional stratigraphic studies--Heaton (1933), Johnson (1945), Reichert (1953), and Waage (1955)--include data from the Devils Head quadrangle. Boos and Boos (1957) include the area in their tectonic study of the Front Range.

Unpublished work in the area consists of theses by Robb (1949), Malek-Aslani (1950), Kinnaman (1954), Ballew (1957), Harms (1958), and Bauer (1959). Bauer's work in the sedimentary portion of the area is excellent; the writer, at the suggestion of his advisor, adopted it for this report with little change.

Currently, G. R. Scott of the U. S. Geological Survey is preparing a detailed report on the Kassler quadrangle; W. L. Peterson of the U. S. Geological Survey is preparing a report on the Platte Canyon quadrangle; and R. M. Hutchinson of the Colorado School of Mines is studying the northern portion of the Pikes Peak batholith. Brief accounts of some of their work have been published; (Scott, 1960; Peterson and Scott, 1960; Hutchinson, 1958a, 1958b, 1959a, 1959b, 1960a, 1960b).

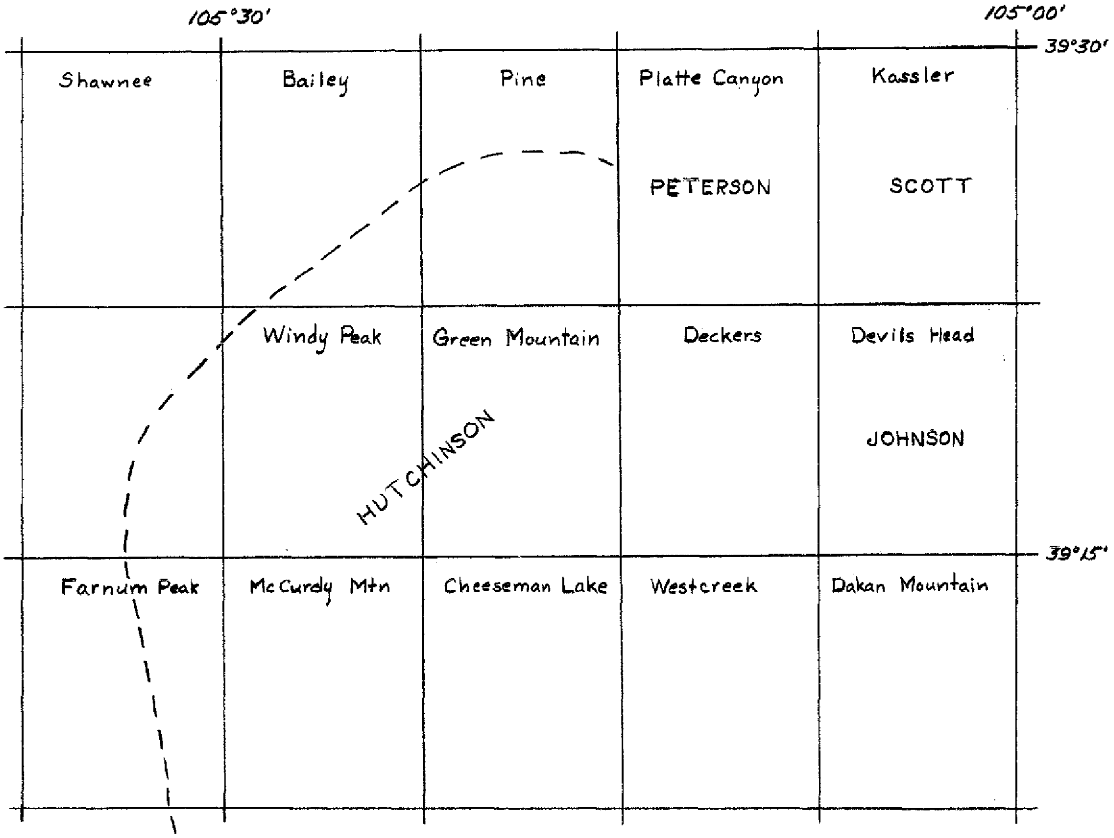


Figure 1. Index map of current geologic mapping in Devils Head vicinity.

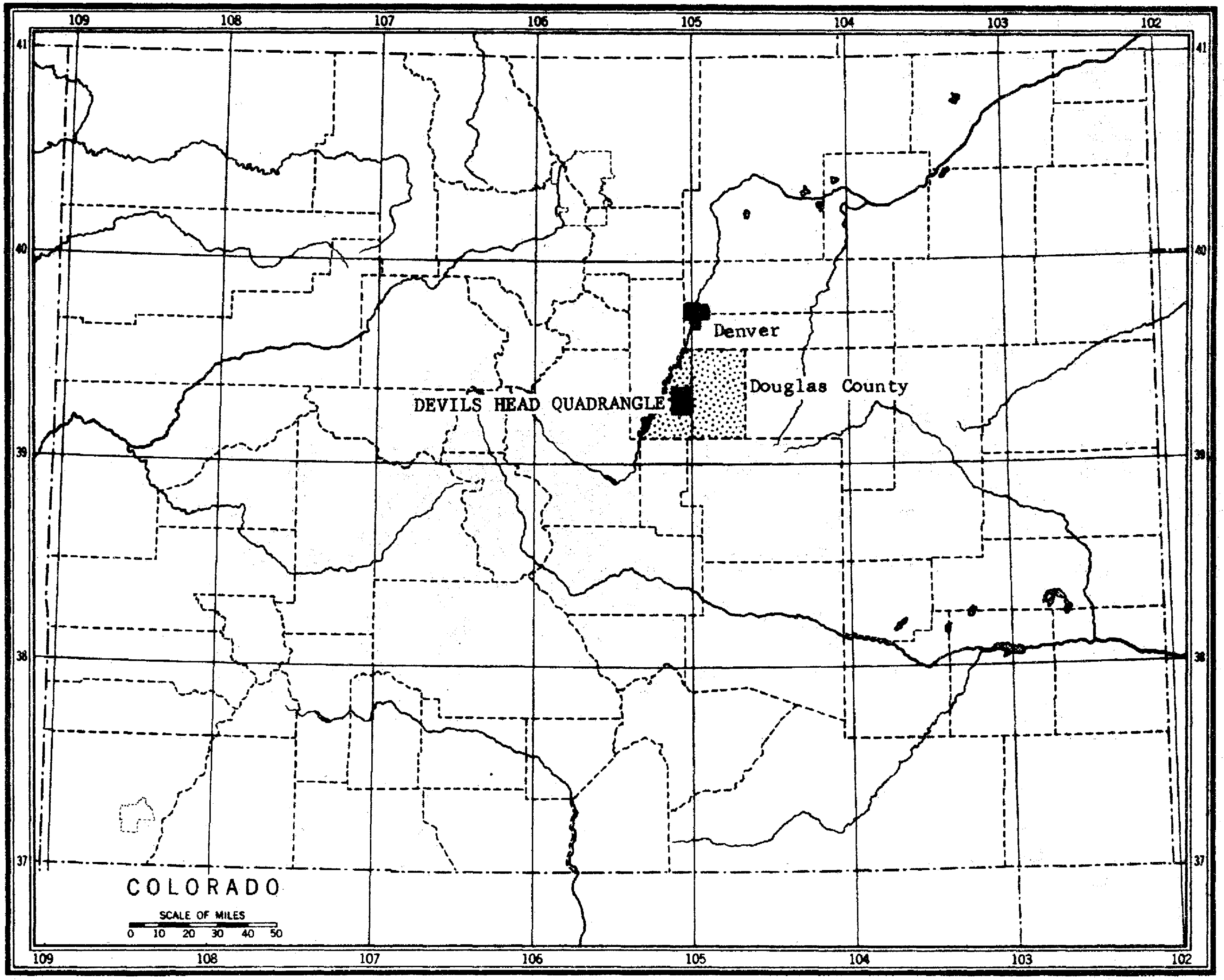


Plate 1. Index Map of Colorado, Showing Location of the Devils Head Quadrangle.

Location and Accessibility

The Devils Head quadrangle, in the U. S. Geological Survey's $7\frac{1}{2}$-minute quadrangle series, is in western Douglas County, Colorado, about 30 miles south of Denver (Plate 1). The quadrangle lies between longitudes $105^{\circ}00'$ and $105^{\circ}07\frac{1}{2}'$ west, and latitudes $39^{\circ}15'$ and $39^{\circ}22\frac{1}{2}'$ north. The Kassler $7\frac{1}{2}$-minute quadrangle adjoins the Devils Head quadrangle on the north. A strip, about three quarters of a mile wide, across the south end of the Kassler quadrangle was included in the area of this study to show the northeastern limit of the Pikes Peak batholith on the map (Plate 2). The mapped area thus includes parts of Townships 8 and 9 South, Ranges 68 and 69 West.

From Denver, the area is reached by proceeding south on U. S. Highway 85 to Sedalia, thence westward on Colorado Highway 67, which passes through the south edge of the Kassler quadrangle and the northwest corner of the Devils Head quadrangle. From just west of Sedalia, Colorado Highway 105 extends south past the east edge of the area to Palmer Lake. A number of farm roads extend from these state highways into the east and north edges of the mapped area, and a county road extends west and southwest from State Highway 105 into the northeast part of the area as far as the boundary of the Pike National Forest, from which point a Forest Service road continues southward along Jackson Creek. From State Highway 67, a Forest Service road extends southward through the west part of the area, meets the Jackson Creek road about a mile and a half south of Devils Head, and continues to Colorado Springs.

Several jeep trails penetrate the area. The state highway, the county road, and most of the farm access roads are kept open all year. Because of heavy snow, the others are generally impassable from late fall until middle or late spring.

Climate and Vegetation

The climate in the area is semi-arid and mild. The mean annual precipitation is about 15 inches. Rains are moderately frequent but generally light and of short duration. Most of the rain falls during April, May, June, and August; most of the snow falls during February and March. The mean annual temperature is about 50°F. The range of temperature is about -30° to 100°F, but days much colder than 0°F or warmer than 90°F are infrequent.

Much of the mountainous part of the area supports a thick cover of trees comprising Ponderosa pine, lodgepole pine, piñon, Douglas fir, Englemann spruce, blue spruce, red cedar, and aspen. Slopes along the eastern mountain front and along the northern edge of the area are covered with scrub oak from 5 to 10 feet high; in many places this growth is penetrable only with great difficulty. Along creeks at lower elevations are willows, poplars, and cottonwoods. Bushes, including chokecherry, wild plum, and others, grow along most streams; and thimbleberries, raspberries, gooseberries, and currants grow in clearings and grassy areas. The lower elevations on the east side of the area support bunch grass and low brush, such as greasewood; higher untimbered areas are covered with thicker meadow grasses.

Methods of Investigation

Field work for this study was carried on during the summers of 1958, 1959, and part of 1960. Laboratory studies were conducted part-time during the winters of 1959, 1960, and 1961.

Geology was plotted in the field on stereo pairs of air photographs, at a nominal scale of 1:20,000, obtained through the Forest Service. The geology was later transferred by tracing onto a base map made from the U. S. Geological Survey's topographic map of the Devils Head quadrangle at a scale of 1:24,000, very nearly the actual scale of the air photographs.

Laboratory procedures, involving studies of rocks and minerals, utilized the petrographic microscope, the Chayes point counter, the Hunt-Wentworth integrating stage, the Vreeland spectroscope, powder X-ray diffraction apparatus, and other techniques. Calculations for indexing X-ray patterns were made on an LGP-30 digital computer. Chemical analyses were purchased.

Acknowledgments

The writer is indebted to so many persons for assistance and encouragement in this study that it is impossible to list them all; many names are omitted here for lack of space rather than for lack of appreciation.

Members of the Geology Department and other faculty members of the Colorado School of Mines offered valuable suggestions and advice throughout this work. The doctoral committee consisted of Professors R. M. Hutchinson, P. H. Keating, M. A. Klugman, F. M. Carpenter, A. G. Pegis, and N. C. Schieltz. Chemical analyses of feldspars were kindly made by Dr. R. E. Bisque and Mr. G. E. Manning of the Chemistry Department. Professor L. J. Prince of the Mathematics Department provided invaluable assistance in developing the program for the digital computer.

To the landowners who gave the writer access to their property, he expresses his gratitude; to those whom he was unable to contact for permission, he offers his apologies for trespassing.

Financial assistance for this study was provided by a generous grant from Sigma Xi-RESA Research Fund and a graduate fellowship from the Sunray-Midcontinent Oil Company. Without this assistance, the work could not have been carried out.

The writer is indebted to Mr. Philippe J. Coudeville, who acted as driver during part of the field work; to Mr. Russell R. Flowers, who assisted with sample preparation; and to Mrs. Marvyl Steffonich, who typed the final manuscript.

To my wife, Marjorie, who assisted in countless ways, and to my family, who suffered without complaint during this work, I am most deeply indebted.

PHYSIOGRAPHY

The Devils Head quadrangle lies on the boundary between two physiographic provinces. The mountainous western part is in the Front Range section of the Southern Rocky Mountain province, and the foothills belt on the eastern edge of the quadrangle is in the Colorado Piedmont section of the Great Plains province. (Fenneman, 1941, p. 31, 98, Pl. I). Because of this division, the area has a wide variety of topographic features.

The mountains, the northern part of the Rampart Range, represent a highly dissected peneplain, which Fenneman (1931, p. 98) termed the South Park peneplain. This surface, at an altitude of a little over 8000 feet, is easily distinguished in the field and is strikingly apparent when viewed from a distance. The Rampart Range road generally follows ridges corresponding to this surface through the area and on south to Colorado Springs. Van Tuyl and Lovering (1935) postulated several partial peneplains in this area. Their interpretations were neither confirmed nor refuted during this study. The simpler explanation of Fenneman is adopted here.

Devils Head projects above this surface as a great angular monadnock, and streams, generally following fault lines and, in places, prominent joint systems have cut steep-sided valleys between the ridges. Relief across these valleys is from 300 to 700 feet in a quarter of a mile. Total relief in the mapped area is about 3570 feet, from an altitude of about 6180 feet at the Hy-Way Hereford Ranch in the northeast corner of the quadrangle to 9748 feet at Devils Head.

On the east the mountains slope abruptly down to the softer sedimentary rocks of the foothills belt. Near the mountain front, where the beds have been strongly tilted by folding and faulting, are hogback ridges of resistant strata separated by shallow valleys cut in softer layers. Where the beds lie more nearly flat, gravel-covered surfaces, which appear to be highly dissected remnants of a former broad pediment, slope gently eastward.

Apparently, the land forms are the result of dissection of a regional peneplain developed on Laramide structures in Pliocene time. Later uplift caused renewed down-cutting, which formed the canyons in the mountains and a lower peneplain on the sedimentary rocks of the Great Plains. Davis (1912, p. 31) recognized two cycles of uplift after the general Great Plains peneplanation, and Van Tuyl and Lovering (1935, p. 1295) recognized several stages of uplift during the canyon-cutting period in the mountains. These separate stages were not distinguished in this study.

The Devils Head quadrangle lies in the South Platte River drainage system. Although no major streams flow through the quadrangle, several small perennial streams and some intermittent streams flow from it. On the west, Deep Creek, Pine Creek, and Bear Creek flow northwest to join the North Fork of the South Platte River a few miles away. On the east, Jackson Creek, Garber Creek, Jarre Creek, and Indian Creek flow northeast and east out of the area to join West Plum Creek, which in turn flows north to the South Platte River near Littleton.

STRATIGRAPHY

The rocks of the Devils Head quadrangle include crystalline rocks of the Precambrian basement and sedimentary rocks ranging in age from Upper Cambrian to Recent. Every geologic system is represented except the Ordovician, Silurian, Devonian and Mississippian. Ordovician and Mississippian rocks crop out just south of the area; similar rocks presumably were once deposited in this area and later eroded away. Silurian and Devonian rocks probably were never deposited here.

Most of the Devils Head quadrangle is underlain by crystalline rocks. The sedimentary rocks form a narrow belt, about a mile wide, along the east edge of the quadrangle.

The total section of sedimentary rocks in the quadrangle is about 13,000 feet thick. Parts of the Fountain formation and the Pierre shale are missing as the result of faulting, and the upper portion of the Dawson arkose has been eroded away. Contacts between individual formations are poorly exposed in most places or not at all, so that thicknesses of individual formations cannot be measured accurately.

Precambrian

The Precambrian rocks rise in a sharp escarpment above the sedimentary rocks, probably as the result of differential resistance to erosion combined with thrust faulting. In most places, the contacts are obscured by slope wash from the escarpment, so the exact position and nature of the contact can only be inferred. North of Jackson Creek the crystalline rocks probably contact the sedimentary rocks along a steeply west-dipping thrust fault. South of Jackson Creek the sedimentary rocks rest nonconformably on a peneplained surface of granite.

Metamorphic rocks are found in the northwest corner of the Devils Head quadrangle proper. A narrow band of metamorphics along the margin of the batholith in the south of Kassler Quadrangle was examined and is included in this area (Plate 2). The rest of the area is underlain by Pikes Peak granite.

The metamorphic rocks were originally laid down as a thick series of sediments, intercalated with andesitic lava flows, intruded by dioritic sills. The primary features of the rocks have been destroyed by metamorphism (Ball, 1906, p. 375-376), and the stratigraphic relationships are largely obscured. Correlation of rock types as beds or strata is uncertain, even over short distances, although recently Boos (1960) attempted to correlate a series of beds over a distance of some 24 miles.

Because their stratigraphic features are obscured and their sedimentary properties have been destroyed, these metamorphosed sediments, assigned to the Idaho Springs formation, will be treated in later sections.

Paleozoic

The Paleozoic rocks of the Devils Head quadrangle include the Sawatch sandstone of Upper Cambrian age; a series of sandstone dikes of probable Upper Cambrian age; the Fountain formation of Pennsylvanian age, the Lyons sandstone of Permian age; and the Lykins formation, the lower part of which is of Permian age and the upper part of which is of Triassic age. Except for the sandstone dikes, Paleozoic rocks are found only on the southeast edge of the quadrangle. Sandstone dikes are found all along the east edge of the area, near the bend of Jackson Creek in the center of the quadrangle and in the northwest corner of the area.

Cambrian

Sawatch sandstone

Nomenclature: The name "Sawatch quartzite" was applied by Eldridge (Emmons, Cross, and Eldridge, 1894) to the sedimentary series, quartzite and sandstone, that immediately overlies the Precambrian rocks in the Anthracite-Crested Butte quadrangles and is widely distributed on the flanks of the Sawatch Range in central Colorado. Similar strata on the east side of the Front Range were distinguished by various names until Richardson (1915) adopted the name "Sawatch" for the basal sandstone in the Perry Park area, and the formation has generally been known as the Sawatch sandstone since.

<u>Lithology</u>: The Sawatch sandstone crops out at only two places in the Devils Head quadrangle--just north of Hog John Gulch in NW$\frac{1}{4}$ sec. 21, T. 9 S., R. 68 W., and just south of Spring Gulch in NE$\frac{1}{4}$ sec. 17, T. 9 S., R. 68 W.

The basal part of the Sawatch consists of white to tan, fine-grained orthoquartzite, generally massive, but with scattered conglomeratic lenses containing pebbles up to 5 mm in diameter. This basal part is overlain by several feet of white to tan, fine- to medium-grained, subangular to rounded quartz sandstone and orthoquartzite with numerous conglomeratic lenses containing quartz and feldspar pebbles up to 8 mm in diameter. Cross-bedding is common throughout this layer. The upper part of the sequence consists of light brown to maroon and white fine- to medium-grained subrounded quartz sandstone. Limonite and hematite are conspicuous in the colored portions, and some argillaceous material is present. Bedding varies from thin to massive, and cross-bedding is present. Bedding varies from thin to massive, and cross-bedding is present in the thicker beds.

Paleontology: No fossils were found in the Sawatch sandstone in this area, but Cross (1894) mentioned a few Upper Cambrian fossils in the Pikes Peak area.

Thickness: At Spring Gulch, the Sawatch is 20 feet thick; at Hog John Gulch, 55 feet. Brainerd, Baldwin, and Keyte (1933, p. 379) mention more than 100 feet in Perry Park and 45 feet near Manitou Springs. Maher (1950, p. 16-19) reported 87 feet at Cove Canyon, 75 feet at Missouri Gulch, and 51 feet at Williams Canyon. The formation apparently thins both north and south from Perry Park. Brainerd, Baldwin, and Keyte felt that the Sawatch sandstone was probably deposited over a wide area, but was partly removed by later erosion. This view accords with the origin proposed by Vitanage (1954) for the sandstone dikes.

Nature of contacts: In the Devils Head quadrangle the Sawatch sandstone rests nonconformably on a nearly planar surface of Pikes Peak granite, and is overlain unconformably by the Fountain formation.

Environment of deposition: Its nearly planar contact with the underlying granite, its high quartz content, its relatively good sorting and rounding, and the presence of cross-bedding indicate that the Sawatch sandstone was deposited in shallow waters of a slowly transgressing sea.

Age and correlation: The Sawatch sandstone (quartzite) is considered to be of Upper Cambrian age by the U. S. Geological Survey (Wilmarth, 1938, p. 1936). It has been correlated with the Ignacio quartzite of southwestern Colorado, the Reagan sandstone of Oklahoma, the Bliss sandstone of the Franklin Mountains of West Texas, and part of the Deadwood formation of Wyoming, all of which are lithologically similar, by Brainerd, Baldwin and Keyte (1933, p. 379), and to the Lamotte sandstone in the subsurface of eastern Colorado and western Kansas by Maher (1951, p. 88).

Upper Cambrian (?)

Sandstone dikes

Nomenclature: Tabular bodies of quartzite and sandstone, that in their form and mode of occurrence have all the characteristics of igneous intrusive dikes, have been observed in many places in the southern Front Range. They were first reported by Cross (1894b), who referred to them as "sandstone dikes," and later workers have adopted this usage, although the rock is more often quartzite than sandstone. No formation name is justified for these dikes because of their relatively small size and sporadic occurrence.

The dikes reported by Cross (1894a) are near Woodland Park. Crosby (1897) found additional dikes around Manitou and Cheyenne Canyon. Finlay (1916) also reported on sandstone dikes in the Colorado Springs quadrangle. Roy (1946) mentioned a belt, 50 miles long, that is characterized by these dikes. Hartman (1951, p. 44) reported sandstone dikes associated with the Ute Pass fault near West Creek. Vitanage (1954) described the occurrence of several dikes along the contact between the Pikes Peak granite and the Idaho Springs formation in the South Platte area. Harms (1958) mapped a number of sandstone dikes along the eastern flank of the southern Front Range. Peterson and Scott (1960, p. 183) mention sandstone dikes in the Kassler and Platte Canyon quadrangles.

Occurrence: In this study, sandstone dikes were found along the eastern edge of the Pikes Peak granite, in the center of the quadrangle near the bend in Jackson Creek, and in the northwest corner of the quadrangle along Colorado Highway 67. In all these occurrences the dikes are in, or immediately adjacent to, fault zones. Similar close association with faulting is pointed out by the writers listed above.

The dikes in this area range in thickness from less than an inch to as much as 40 feet; some of them tend to pinch and swell. The average width is about 5 feet. They are largely covered by granite wash or soil, so that they cannot be traced for any distance along strike. Most of those seen were exposed for only a few feet, others for a few tens of feet, and one was traced definitely for nearly 400 feet, and either it or related dikes were traced along the same strike for another 600 feet.

The dikes generally trend within a few degrees of north, parallel or sub-parallel to the fault zones with which they are associated, and most of them are nearly vertical, although a few dip as low as 60°W. In places the dikes seem to be more resistant than the granite and stand a few inches to a few feet above the surface, but in most places they seem to weather at the same rate or slightly faster than the granite and exposures are poor. Probably other, concealed dikes occur in the area; quartzite float identical to the dike rocks was found in several places where no dikes were seen.

Most of the dikes appear to be simple tabular bodies, but some of them are distinctly warped and a few split and rejoin around small horses of granite. Contacts with the granite, where they can be clearly seen, are generally sharp. Along Colorado Highway 67, in NW$\frac{1}{4}$ sec. 16, T. 8 N., R. 69 W., a sandstone dike has been intruded by a mafic igneous dike, now highly altered. Post-dike faulting is indicated by slickensides and brecciation in some of the dikes.

Lithology and internal structure: In texture and composition, the sandstone dikes are practically indistinguishable from the Sawatch sandstone. The rocks of the dikes are predominantly light tan and brown to purplish orthoquartzites with some firmly cemented to friable sandstone. The texture generally is fine- to coarse-grained with moderate to good sorting and rounding. The grains are chiefly quartz, with a little feldspar, chalcedony, and mica. The cement is largely iron oxides and silica. Fresh, angular to subangular, pebble-sized fragments of granite are abundant in some dikes, particularly along the walls.

Some of the dikes show rather poorly defined banding, similar to bedding, parallel to the walls of the dike; and elongate granite inclusions are aligned more or less parallel to the walls. No horizontal layering was observed. Jointing tends to be parallel to or perpendicular to the walls, except in the more massive dikes, where there is a tendency toward warped fractures rather than planar joints.

Origin and age: Clastic dikes, known for more than a century, seem geologically anomalous; many of them have been described and numerous attempts to explain them have been made. Newsom (1903) reviewed the literature on clastic dikes up to that time and listed the known dike rocks and the types of enclosing rocks. He also tabulated (p. 268) the probable modes of formation of such dikes as follows:

a. By injection from below, along with water, petroleum or petroleum residues. Injection due to hydrostatic pressure, pressure from overlying beds, pressure from gas, or combinations.

b. By injection from above.

c. By material being let down gradually from above, synchronously with the slow formation (by leaching of water) of openings in underlying calcareous rocks.

e. By deposition of sediments in fissures, partially or entirely under the sea.

Newsom regarded injection from below as the most common origin; he described a number of dikes formed in that way. Diller (1890) had previously explained some dikes in California as originating during earthquakes (faulting) by the filling of fractures from below with the aid of abundant water. He cited the sand fountains and similar phenomena actually observed during earthquakes.

Crosby (1897) explained the dikes of the Ute Pass area as being formed by settling of overlying, unconsolidated Potsdam (Sawatch) sands into fissures opened by movement along the Ute Pass fault, and by sinking of narrow sheet-like graben of granite with their overlying sands.

Roy (1946) believed the dikes were formed in connection with thrust faulting; quicksand-like material, derived from the sedimentary rocks of the downthrown block, was injected upward into fissures in the crystalline rocks of the upthrown block.

Monroe (1951) described some dikes in Texas that were formed by marine sediments deposited in tension cracks opened along the sea floor.

Vitanage (1954) called upon the injection from above into fissures opened by submarine faulting, after the wall rocks had been covered by sediments but before those sediments were indurated. Force for injection was supplied by the weight of overlying beds.

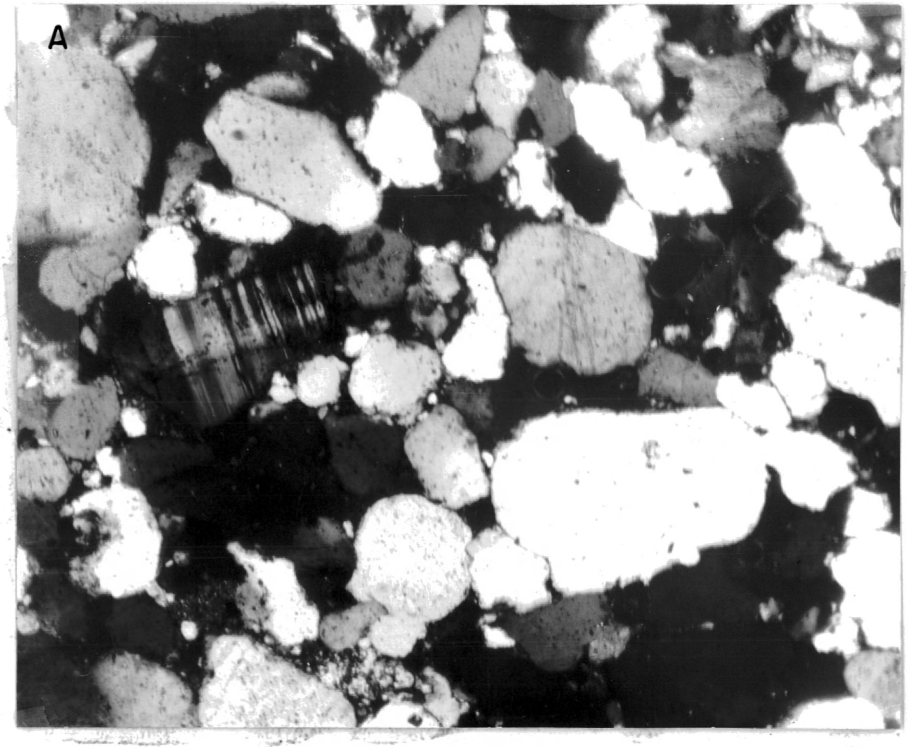
Harms (1958) believed the dikes to be of Laramide age because of their association with Laramide faults. He attributed the dikes to the injection of water-saturated sands upward and downward into overthrust masses of granite. In a talk before the Rocky Mountain Section, Geological Society of America, in Golden, Colorado, 8 May 1958, he explained that the sands were derived from the disaggregation of pre-Laramide sandstones by the forces of faulting.

From the present study it is believed that the lithology and structure of the dikes in this area offer clear proof of their origin. They must have been injected downward, as a slurry of unconsolidated Sawatch sands, into fissures formed by faulting in late Sawatch or early post-Sawatch time. This conclusion would date them as Upper Cambrian or perhaps Lower Ordovician.

The absence of horizontal bedding, the flow banding parallel to the walls, and the orientation of inclusions parallel to the walls indicate their formation by injection rather than by sedimentation. It is most unlikely that fissures as large as some of the dikes could remain open and unfilled, since the dikes must have been injected concurrently with the opening of the fissures.

The sands must have been injected from above because there is no downward source for them. Sands in the Idaho Springs formation could not have remained unconsolidated during intrusion and consolidation of the granite, and there is no evidence that the granite mushroomed out over part of the Idaho Springs formation. Derivation of the sands from the sedimentary rocks in the footwall block of the Golden-Front Range thrust fault is untenable. Even with a dip as low as 10 degrees, the sole of the fault would lie nearly a mile deep along the western edge of the Devils Head quadrangle, and at the dike near Pine, Colorado (Vitanage, 1954, p. 496) the sole would be nearly 2½ miles deep. Upward injection of slurry over such distances is highly improbable. Moreover, the best evidence indicates that the thrust fault in the Devils Head quadrangle actually dips 50 degrees or more. Although these objections are less valid for those dikes near the eastern edge of the granite, it is unreasonable to postulate different origin for dikes so manifestly similar.

The lithological similarity of the dike rocks to the Sawatch sandstone was recognized by Crosby (1897, p. 140) and Vitanage (1954, p. 500). These writers also pointed out dissimilarities to other sandstones in the region. Examinations of specimens of Sawatch sandstone and of sandstone dikes, collected within 100 yards of each other, demonstrate the



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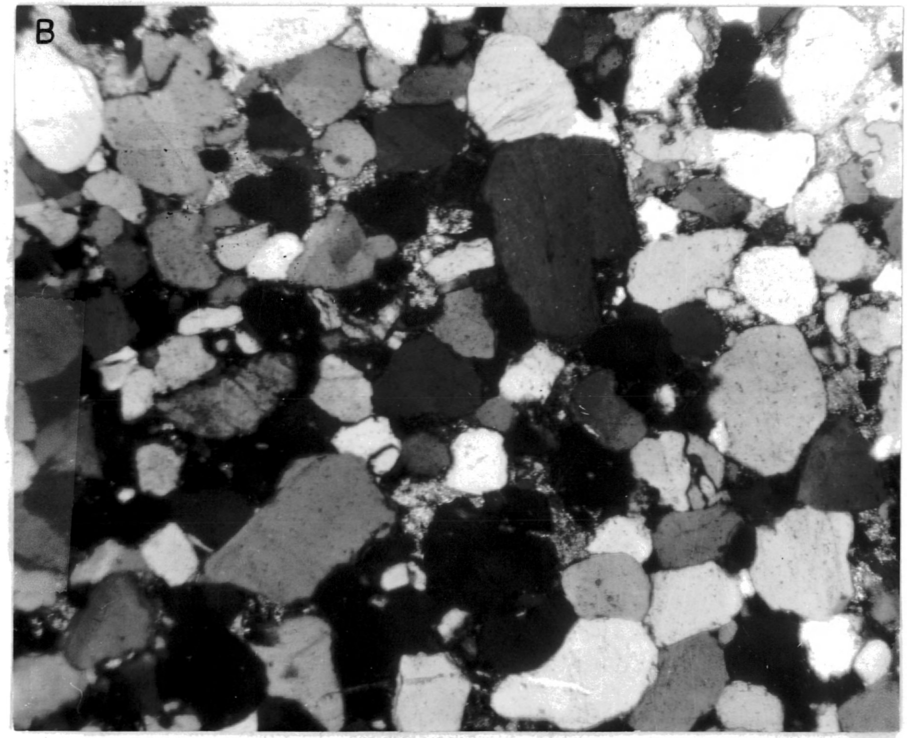

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Figure 2. Photomicrographs of Sawatch sandstone (A) and sandstone dike (B), showing lithologic similarity.

essential identity of the two.

The dikes cannot be of Laramide age. By Laramide time the Sawatch sandstone must have been thoroughly indurated, as indeed were the Fountain, Lyons, and Dakota formations, even though these latter formations are not considered possible sources. To derive the sands for the dikes from any of these formations would involve crushing and disaggregation, and the dikes should everywhere contain crushed and brecciated fragments of these formations. Instead, except for clearly post-dike slickensides and brecciation in some places, the dikes are unfractured sandstones and quartzites, clearly deposited as individual sand grains. Moreover, Laramide faults cut all the pre-Laramide rocks of the area, and if the dikes were of Laramide age, sandstone dikes could be expected in the Paleozoic and Mesozoic rocks. The only dikes ever reported have all been in Precambrian rocks. The association of the dikes with Laramide faults is explained by the fact that Laramide faulting in many cases involved renewed movement along earlier fractures, some of them dating back to Precambrian.

By late Cambrian time, an extensive, very flat peneplain had been developed on the surface of the Pikes Peak granite and the Idaho Springs formation in this region. On this surface, a slowly transgressing sea deposited the Sawatch sands over a much wider area than is now represented by the distribution of outcrops of Sawatch sandstone. After the deposition of a considerable thickness of Sawatch sands, and perhaps of later sediments, but prior to induration of the basal Sawatch sands, faulting opened fissures, in the underlying crystalline rocks, into which the Sawatch sands were injected by the weight of overlying beds. Whether the faults were newly initiated, or whether they represented renewed movement on pre-existing fractures is not known. After the faulting, but prior to the deposition of the Fountain formation in Pennsylvanian time, erosion removed the Sawatch sandstone from much of its former area. Lovering and Johnson (1933, p. 361-363) indicate an unconformity between the Sawatch sandstone and the Manitou dolomite of Lower Ordovician age. Maher (1951, p. 88) and LeRoy (1961) place the unconformity above the Manitou dolomite and below the Harding sandstone of Middle Ordovician age. Other pre-Fountain unconformities are also mentioned by these writers. The sandstone dikes therefore must be younger than the basal Sawatch sandstone and older than the basal Fountain formation, probably older than the Harding sandstone or the Manitou dolomite. They are here tentatively dated Upper Cambrian.

Pennsylvanian

Fountain formation

Nomenclature: The Fountain formation was named by Cross (1894a) from its exposures on Fountain Creek in the Pikes Peak and Colorado Springs quadrangles. At the type area it consists of a series of red sandstones, grits, and conglomerates.

Lithology: The Fountain formation comprises a series of interstratified red, maroon, and gray arkoses, conglomerates, feldspathic sandstones and siltstones. In this area, the basal portion tends to be gray to white, and the rest is red or maroon with local bleached areas. The formation is highly irregular and cross-bedded throughout so that individual beds cannot be traced extensively. The lower part of the formation contains more conglomerate than the upper part, and the grade size in the conglomerates tends to be coarser. Fine-grained sandstone and siltstone lenses are more abundant in the upper part.

The chief minerals are quartz and pink feldspar, with small amounts of biotite and muscovite, and accessory magnetite, tourmaline, zircon, garnet, and staurolite. In the conglomerates are rounded cobbles, up to 4 inches in diameter, of granite, gneiss, schist and quartzite. The red color is due to hematitic coatings on the mineral grains, to pink and light red feldspar grains, and bright to dark red argillaceous material interstitial to the grains.

Paleontology: No fossils have been found in this part of the Fountain formation. Finlay (1907) reported Lower Pennsylvanian plant fossils from the Glen Eyrie shale, considered by the U. S. Geological Survey and others (Hubert, 1960, p. 31) to be a lower member of the Fountain formation. In 1957, a few miles southeast of the Devils Head quadrangle, Ellis (1958) found a marine fauna of early Pennsylvanian age in the lower part of the Fountain formation.

Thickness: The true thickness of the Fountain formation cannot be measured in the Devils Head quadrangle, for the formation is cut by faults throughout its exposed distance, and no subsurface measurements have been made. Ballew (1957, p. 18) measured 2200 feet at Roxborough Park, and Malek-Aslani (1950, p. 32) reported 3000 feet in southern Perry Park. Hubert (1960a, p. 75) reported 1928 feet at Roxborough Park and 4526 feet at the Garden of the Gods. Interpolation between these figures indicates that the thickness of the Fountain formation in the Devils Head quadrangle should be about 2500 feet.

Nature of contacts: South of Spring Gulch, the Fountain formation rests unconformably on the Sawatch sandstone of Upper Cambrian age. North of Spring Gulch, the Fountain rests nonconformably on Pikes Peak granite of Precambrian age. The top of the Fountain formation is transitional with the Lyons sandstone of Permian age.

Environment of deposition: The Fountain formation is generally believed to be of continental, fluviatile origin. Hubert (1960b) described it as consisting of alternating lenses of stream-channel, stream flood-plain, and deltaic-lacustrine sediments. Ellis' (1958) discovery of marine fossils indicates that a sea lay a short distance east of this area and that the Fountain may be of marine origin farther east.

Age and correlation: The Fountain formation overlies the Glen Eyrie shale of Early Pennsylvanian age (Finlay, 1907; Hubert, 1960a, p. 32-33) and contains Early Pennsylvanian marine fossils in its lower part (Ellis, 1958). The top of the formation interstratifies with the Ingleside formation (Lavington and Thompson, 1948, p. 38). Hubert (1960a, p. 34) believes the thicker portions of the Fountain formation may include some beds of Permian age.

The Fountain formation is correlated with part of the Casper formation of Wyoming, with the Belden formation and part of the Maroon formation of central Colorado, and with part of the Sangre de Cristo series in southern Colorado.

Lyons sandstone

Nomenclature: The Lyons sandstone was named by Fenneman (1905, p. 23) for its exposure near Lyons in Boulder County. Eldridge (Emmons, Cross, and Eldridge, 1896, p. 52) designated beds overlying the Fountain formation in the Denver Basin as the "Creamy" sandstone, and Richardson (1915) considered these beds in the Perry Park area as equivalent to the Lyons. Levington and Thompson (1948, p. 40) found "Creamy" sandstone interstratified with Lyons sandstone, and the name Lyons has been generally adopted.

Lithology: The basal part of the Lyons, transitional into the Fountain formation, is characterized by lenses of coarse-grained arkosic sandstone interbedded with very fine-grained feldspathic sandstone. The middle portion consists of brick-red, very fine-grained sub-rounded quartz sandstone consisting of quartz, minor feldspar, and traces of zircon, leucoxene, staurolite, tourmaline, magnetite, and other heavy minerals. The upper part of the Lyons has scattered lenses of conglomerate containing angular granules of quartz and feldspar, and rounded 1- to 8-centimeter pebbles of granite and a fine-grained red sandstone. The Lyons sandstone in the Devils Head quadrangle tends to be massive, without the lamination and prominent cross-bedding that characterizes the formation elsewhere. Some poorly developed cross-bedding is present.

The Lyons weathers to form irregular hog-back ridges. Numerous fractures filled by later silica weather out on outcrop surfaces to give the rock a veined appearance.

Paleontology: No fossils except amphibian and scorpionid tracks (Thompson, 1949, p. 63-64) have been found in the Lyons formation.

Thickness: The Lyons sandstone is 310 feet thick in sec. 32, T. 7 S., R. 68W., and 250 feet thick in sec. 15, T. 8 S., R. 68 W. Between these sections, the Lyons is cut by numerous faults and is absent in many places, therefore it is not known whether the change in thickness is due to wedging during deposition or to other causes.

Nature of contacts: The lower contact of the Lyons sandstone is transitional to the Fountain formation through 10 to 15 feet of interstratified sandstone and arkose. The poorly exposed upper contact with the Lykins formation is believed to be sharp and conformable. Hubert (1960a, p. 35) considers this contact to be generally transitional with local disconformities.

Environment of deposition: The pronounced cross-bedding and frosted grains in the Lyons led Tieje (1923) to ascribe an aeolian origin to the formation. Swash marks, rhomboid ripple marks, bubble impressions, animal tracks, and other primary sedimentary features indicated a beach origin to Thompson (1949). LeRoy (1946, p. 30) suggested a partially submerged off-shore bar. Probably the Lyons is a strand-line deposit in which all these environments were represented.

Age and correlation: Lacking fossil evidence, the Lyons sandstone must be dated by indirect stratigraphic evidence. Heaton (1933, p. 123) traced the Lyons northward into Wyoming where it feathers out into the Satanka shale of Permian age. Maher (1954, p. 2234) assigns a Permian (Leonard) age to the Lyons, correlating it with the Cedar Hill sandstone, Salt Plain formation, and Harper sandstone of western Kansas. Thompson (1949, p. 71-72) tentatively correlates the Lyons with the Kaibab limestone and Coconino sandstone of the Colorado Plateau, and with upper Weber sandstone in northwestern Colorado

Permo-Triassic

The boundary between the Paleozoic and Mesozoic eras is generally defined as lying within the Lykins formation. LeRoy (1946, p. 31) placed the boundary between the Glennon limestone and Strain shale members of the Lykins.

Lykins formation

Nomenclature: The Lykins formation was named by Fenneman (1905, p. 24) from its exposure along Lykins Gulch in Boulder County. LeRoy (1946, p. 31) subdivided the Lykins into five members named for geographic features near Morrison, Jefferson County. In ascending order the members are the Harriman shale, the Falcon limestone, the Bergen shale, the

Glennon limestone, and the Strain shale. All five members have been recognized in the Devils Head quadrangle.

Lithology: The Harriman shale consists essentially of a red silty shale. In sec. 31, T. 7 N., R. 68 W., an 8-inch bed of white, fine-grained calcareous sandstone overlain by a 3-inch bed of gray crystalline limestone occurs 2 feet above the base of the Harriman shale member.

The Falcon limestone is a finely crystalline, thinly laminated, pink-to-white dolomitic limestone.

The Bergen shale, poorly exposed, consists of red, somewhat silty, shale. In sec. 10, T. 9 S., R. 68 W., the middle portion of the Bergen shale contains a 1-foot bed of massive white gypsum under which is 1.5 feet of pink, finely crystalline, arenaceous limestone and 5.5 feet of white, finely crystalline, vuggy gypsum.

The Glennon limestone consists of a lower white argillaceous dolomitic limestone or calcareous dolomite characterized by contorted laminae, and an upper finely laminated, argillaceous pink limestone. The lower unit is the "Crinkled sandstone" or "Crinkled limestone" of earlier writers.

The Strain shale is poorly exposed. The lower portion appears to be soft, red, slightly calcareous shale with thin beds of white satin-spar gypsum. The upper portion is light-red massive gypsiferous, calcareous siltstone alternating with thin beds of soft gray-green shale.

Paleontology: No fossils were found in the Lykins formation during this study. Thompson (1949, p. 71-72) alludes to invertebrate remains of Permian age from a thin limestone above the Lyons (Creamy) sandstone in Perry Park. The limestone is probably either Falcon or Glennon.

Thickness: The Lykins formation is 210 feet thick in sec. 31, T. 7 S., R. 68 W., and 190 feet thick in sec. 10, T. 9 S., R. 68 W. Individual members vary markedly in thickness from one section to the other, except for the Falcon limestone, which has a constant thickness of about five feet. LeRoy (1946, p. 44) found similar variations in the thicknesses of the individual members.

Nature of contacts: The contact of the Lykins formation with the Lyons sandstone is sharp and probably conformable. The contact with the Ralston Creek formation was not observed. LeRoy (1946, p. 42) reported a transitional contact between these formations in the Golden-Morrison area, and Malek-Aslani (1950, p. 49) reported a transitional contact in southern Perry Park.

Environment of deposition: Tieje (1923, p. 205) believed the Lykins formation to be the result of deposition in the upper reaches of a delta. Heaton (1933, p. 149) ascribed the formation to shallow marine deposition. LeRoy (1946, p. 47) believed that the Lykins was rapidly deposited under a uniform aqueous environment, possibly in close relation to the sea, but not under normal marine conditions.

Age and correlation: LeRoy (1946, p. 44) assigned a Permian age to that part of the Lykins formation below the top of the Glennon limestone and a Triassic age to the Strain shale. Heaton's correlation of the "Crinkled" (Glennon) with the Forelle limestone (Permian) of Wyoming and Thompson's (1949, p. 71) report of Permian fossils in a Lykins limestone bed in Perry Park support this assignment. Lavington and Thompson (1948, p. 44) consider the upper Lykins beds (Strain shale) to be of Triassic age on the basis of stratigraphic position and mode of origin.

Mesozoic

Besides the Strain shale, rocks deposited in the Devils Head quadrangle during the Mesozoic era include the Ralston Creek formation and the Morrison formation of Jurassic age; and the Dakota formation, the Benton formation, the Niobrara formation, the Pierre shale, the Fox Hills sandstone, and the Laramie formation, of Cretaceous age. The lower part of the Dawson arkose represents the transition between the Mesozoic and Cenozoic eras.

Jurassic

Ralston Creek formation

Nomenclature: LeRoy (1946, p. 47) defined the Ralston formation to include the strata between the red

Strain shale of the Lykins formation and the basal sandstone of the Morrison formation. Earlier writers had included these beds in the Lykins formation (Richardson 1915; Lee 1927, p. 28) or in the Morrison formation (Heaton 1939, p. 1160). Van Horn (1947) changed the name to Ralston Creek formation, a change accepted by LeRoy (1961). The name is taken from exposures on Ralston Creek in Jefferson County.

Lithology: Two lateral variations, a shale-marlstone facies and a gypsiferous facies, were recognized by LeRoy (1946, p. 47-48). Both facies are found in the Devils Head area. North of Jarre Canyon the shale-marlstone facies is present on the west slope of the Dakota hogback. The basal 4 feet consists of soft light-gray argillaceous calcareous siltstone. Above this is 20 feet of poorly exposed red and gray-green silty marlstone. The rest of the formation is covered by slope wash.

From sec. 4, T. 9 S., R. 68 W., southward, the gypsiferous facies forms low hogbacks offset by faulting. The formation consists of about 60 feet of interbedded soft, powdery gray gypsiferous shale and white gypsum that varies from satin spar to very finely crystalline and massive. Thin beds of light-red and gray-green shale are present in the lower portion.

Paleontology: No fossils were found in the Ralston Creek formation in the Devils Head area. LeRoy (1946, p. 51, 55) reported Aclistochara and Ostrea in the shale marlstone facies at Ralston Creek.

Thickness: The Ralston Creek formation is estimated to be about 60 feet thick in this area. Accurate determination of the thickness is prevented by cover.

Nature of contacts: Although poorly exposed in this area, the contact between the Ralston Creek formation and the Lykins formation appears to be transitional. Because the contact between the Morrison formation and the Ralston Creek formation is covered in this area, its nature could not be determined. LeRoy (1946, p. 53) reported a sharp erosional contact near Morrison, Jefferson County.

Environment of deposition: LeRoy (1946, p. 55) attributed the shale-marlstone facies to deposition in a quiet fresh or brackish water environment, and the gypsiferous facies to deposition in a shallow closed or partly closed aqueous body. Lagoonal or estuarine conditions would fit these environments.

Age and correlation: The Ralston Creek formation is tentatively assigned a Jurassic age on the basis of its closer resemblance to the Morrison than to the Lykins and on the occurrence of *Aclistochara* in both the lower Morrison and upper Ralston Creek formations.

Morrison formation

Nomenclature: The Morrison formation was named by Eldridge (Emmons, Cross, and Eldridge 1896, p. 60) for its occurrence near Morrison, Jefferson County. Waldschmidt and LeRoy (1944) redefined the formation, and suggested transferring the type section from "near Morrison," where it is poorly exposed to a site north of Morrison where there is an excellent exposure. This suggestion has been generally adopted.

Lithology: The Morrison formation is poorly exposed in the Devils Head area. In sec. 31, T. 7 S., R. 68 W., the basal Morrison consists of 5 feet of light-gray, very fine-grained calcareous feldspathic sandstone. Above it is a 220-foot zone covered by gray clay soil with some reddish bands. The upper 130 feet of the formation consists of alternating variegated red, gray-green and yellow-brown shales and gray-green, brown, pink and maroon very fine-grained friable argillaceous sandstone and siltstone.

In the Perry Park area, the Morrison is generally covered by a gray clay soil. Outcrops of soft, gray calcareous shale are scattered near the base of the formation. Johnson (1954, p. 94) mentioned a large lense of chara limestone that occurs in the Morrison in Perry Park. He did not give a definite location, and the bed was not observed during this study. The limestone may be southeast of the Devils Head quadrangle.

Paleontology: No fossils were found in the Morrison during this study. Johnson (1954, p. 94) has reported Charophytes from the basal Morrison in Perry Park, and LeRoy

1946, p. 60) reported _Aclistochara_ and a few poorly preserved fresh-water gastropods and ostracods from the lower Morrison. Dinosaur tracks and bones were found abundantly in the upper part of the formation near Morrison, and plant remains have been reported from many places.

Thickness: The Morrison formation is about 350 feet thick in this area.

Nature of contacts: The contact between the Ralston Creek formation and the Morrison formation is too poorly exposed in this area for its nature to be determined. The Morrison-Dakota contact is also poorly exposed, but a distinct change in lithology and a basal conglomerate within the Dakota suggest an unconformity. Most workers have recognized an unconformity at the base of the Dakota elsewhere in this region.

Environment of deposition: The Morrison formation is of continental origin. The land probably consisted of flat lowlands covered by fresh water lakes and swamps in which were deposited the variegated shales, marls, siltstones, limestones and sandstones of the Morrison formation.

Age and correlation: The Morrison has been dated as upper Jurassic in age on the basis of the vertebrate fossils collected from the sandstone beds. As used in this report, the Morrison includes beds considered to be lower Cretaceous in age by Waage (1955, p. 23-26).

Cretaceous

Dakota formation

Nomenclature: The Dakota formation was named by Meek and Hayden (1861, p. 419-420) for exposures in Dakota County, Nebraska. Stose (1912) divided the Purgatoire formation off from the Dakota in the Apishapa quadrangle, and Richardson (1915) and Robb (1949) mapped Purgatoire in the Perry Park area. Waage (1955) considered the Dakota to be a group including the Lytle formation and the South Platte formation. Inasmuch as the Lytle formation apparently was included in the Morrison by Waldschmidt and LeRoy (1944) and as it could not be separated from the Morrison in this area, Bauer (1958) mapped the Morrison to include the Lytle, and mapped Waage's South Platte formation as Dakota formation. That usage is followed here.

Lithology: Waage (1955, p. 28) divided the Dakota (South Platte) formation into a number of subdivisions, most of which can be recognized in this area. The members are described in ascending order.

The basal Plainview sandstone member consists of 15 feet of gray-to-tan chert and quartz pebble conglomerate with pebbles 0.5 to 1 cm in a matrix of medium- to coarse-grained sand. It is overlain by 30 feet of brown silicified shale and purple siltstone.

The third shale member is poorly exposed, but appears to consist of about 35 feet of red silty shale.

The third sandstone member is a white to tan thick-bedded fine-grained sandstone about 50 feet thick. Its lower portion contains granules of quartz and chert.

The second shale member is covered in this area. According to Waage (1955, p. 28), it consists of gray shale and minor siltstone.

The Kassler sandstone member is predominantly massive light-gray to brown, fine-grained sandstone. Lenses of intraformational conglomerate consisting of clay-shale fragments in a sandy matrix occur in the middle of the member and some light-gray siltstone in the upper and lower portions.

The Van Bibber shale member consists of 10 feet of gray-brown thin-bedded platy shale containing abundant plant fragments.

The first sandstone member consists of 55 feet of massive and crossbedded gray, very fine-grained quartz sandstone. The upper 15 feet contains interbedded dark-gray calcareous shale and forms a transition zone to the Benton formation.

Owing to its occurrence between two less resistant formations, the Benton and the Morrison, the Dakota typically stands as prominent hog-back ridges throughout much of the Front Range foothills belt.

Paleontology: Only unrecognizable plant remains and silicified wood fragments were found in the Dakota formation in the Devils Head quadrangle, but Waage (1955, p. 31) reported marine fossils, especially *Inoceramus comancheanus* Cragin and *Pteria salinensis* White, in the basal second shale member in the Kassler quadrangle.

Thickness: The Dakota formation is about 350 feet thick in the Devils Head area.

Nature of contacts: The contact between the Dakota formation and the underlying Morrison formation (the South Platte-Lytle contact of Waage, 1955) is poorly exposed but is believed to be an unconformity. It is called a disconformity by Waage (1955, p. 26). The contact between the Dakota and the Benton formations is transitional through 15 feet of interbedded sandstone and shale.

Environment of deposition: The Dakota formation of the Devils Head area was deposited under near-shore continental conditions, except for a limited marine phase within the second shale member. Lovering (1929) explained the deposition of the Dakota by the slow transgression of a sea over a gently sloping piedmont plain covered with widespread swamps.

Age and correlation: The Dakota formation is dated as of Early Cretaceous age on the basis of small molluska fauna in its marine phases.

Colorado Group

The Colorado group was named by Hayden (1876, p. 45) to include the Fort Benton, Niobrara, and Fort Pierre formations. White (1878, p. 21) excluded the Fort Pierre from the Colorado group, and today the term is generally applied to the Benton and Niobrara formations.

Benton formation

Nomenclature: Meek and Hayden (1861, p. 419-421) applied the name Fort Benton to the Formation No. 2 of Cretaceous age near Fort Benton, Montana. The "Fort" has been generally dropped from the name. Gilbert (1896, p. 564-565) divided the Benton in southern Colorado into three members, in ascending order the Graneros shale, the Greenhorn limestone, and the Carlile shale. Bass (1926, p 28) applied the name Codell sandstone to the upper sandy portion of the Carlile shale in western Kansas.

Lithology: Except for a limestone equivalent to the Codell member, the Benton is poorly exposed in the Devils Head area. The Graneros, Greenhorn, and Carlile members can be identified only in scattered exposures in gullies.

The Graneros shale consists of light-brown calcareous shale and dark gray to black non-calcareous shale interbedded with thin soft, massive yellow-brown, very fine-grained quartz sandstones.

The Greenhorn limestone appears to be represented by a series of alternating thin, gray, argillaceous limestones and light-brown calcareous shales.

The Carlile shale, where exposed, is light-brown calcareous shale.

The Codell member of the Benton formation in this area consists of a 3-foot bed of dense light-brown, medium-crystalline thin-bedded limestone. Dane, Pierce, and Reeside (1937, p. 217) reported a similar limestone, equivalent to the Codell sandstone, at several localities in the Arkansas Valley.

Paleontology: Inoceramus labiatus Schlotheim was identified from the Codell member, and fragments of Inoceramus and Ostrea were found in the Codell and Greenhorn members.

Thickness: The Benton formation is about 590 feet thick in the Devils Head quadrangle.

Nature of contacts: The Benton formation is transitional downward into the Dakota formation through a 15-foot zone of interbedded shale and sandstone. The contact between the Benton and Niobrara formations, marked by a distinct lithologic break, is classed as a disconformity by Johnson (1930).

Environment of deposition: The Benton formation was deposited in shallow marine waters, probably some distance from shore (LeRoy, 1946, p. 78).

Age and correlation: The Benton formation has been dated as Upper Cretaceous on the basis of its abundant marine fauna. It is correlated with part of the Colorado shale of

Montana; the Mowry and Thermopolis formations of Wyoming; and part of the Mancos shale of western Colorado, Utah, and New Mexico (Heaton, 1950, p. 1660-1661).

Niobrara formation

Nomenclature: The name Niobrara was applied to the Formation No. 3 of the Cretaceous by Meek and Hayden (1861, p. 419, 422). The name was derived from the exposures near the mouth of the Niobrara River in Knox County, Nebraska. Gilbert (1896, p. 566-567) divided the Niobrara into a lower Timpas limestone member and an upper Apishapa shale member.

Williston (1893, p. 108-109) proposed the term Fort Hays limestone member for the lower Niobrara in western Kansas, and Cragin (1896, p. 51) applied the name Smoky Hill marl to the upper Niobrara in Kansas. The terminology, used by the U. S. Geological Survey in western Kansas and eastern Colorado, has been extended to the Front Range by some geologists (LeRoy and Schieltz, 1958, p. 2447).

Lithology: The Niobrara formation is very poorly exposed in the Devils Head area. Where it can be seen, the Timpas limestone consists of massive buff to white chalky argillaceous limestone interbedded with thin, soft, light-gray marls. Small pyritic concretions are scattered through the lower portion of the member.

The Apishapa shale is covered in this area. Ballew (1957, p. 52) described it a short distance north of the

Devils Head quadrangle as a buff, thin-bedded, highly calcareous, foraminiferal shale.

Paleontology: Scattered fish scales were found in the Timpas limestone along with the mollusks *Inoceramus deformis* Meek, *Inoceramus labiatus* Schlotheim, and *Ostrea congesta* Conrad.

Thickness: Because of its poor exposure and its gradational contact with the Pierre shale, the thickness of the Niobrara formation could not be measured in this area. A well, the F. G. Holl No. 1 Greenland Land and Cattle Co., disclosed 480 feet of Niobrara in sec. 17, T. 10 S., R. 68 W. A thickness of 500 feet has been assumed for this report.

Nature of contacts: The contact between the Niobrara and Benton, marked by a distinct lithologic break, appears to be a disconformity (Johnson, 1930). The contact between the Apishapa shale member of the Niobrara and the Pierre shale is covered in this area. In 1946, LeRoy (p. 79-81) stated that the contact in the Golden-Morrison area is lithologically transitional but that the formations could be distinguished by microfossils. Later, on the basis of micropaleontology and X-ray studies, LeRoy and Schieltz (1958, p. 2463) reported an unconformity at the Niobrara-Pierre contact.

Environment of deposition: The Niobrara formation is of marine origin deposited on a shallow shelf in an open sea during Timpas time and under neritic conditions with open circulation during Apishapa time.

Age and correlation: The fauna of the Niobrara formation dates it as Upper Cretaceous. The Niobrara is correlated with part of the Mancos shale and the Gallup sandstone in the San Juan Basin, New Mexico, parts of the Hilliard and Baxter shales in Wyoming, and part of the Colorado shale of Montana (Weimer, 1960).

Montana Group

The Montana group was named by Eldridge (1888, p. 93) to include the Pierre shale and the Fox Hills sandstone.

Pierre shale

Nomenclature: The name Fort Pierre was given by Meek and Hayden (1861, p. 419, 424) to the Formation No. 4 of the Cretaceous near Fort Pierre, South Dakota. The "Fort" has been generally dropped from the name.

Lithology: The Pierre shale is a thick series of light-gray to black shales and silty shales. Thin lenses of nodular gray argillaceous limestone occur throughout the section. Thin bentonite beds are scattered through the formation, and the upper portion contains a number of sandy shales that were formerly included in the Fox Hills sandstone. A fossiliferous zone of sandy shale that Bauer (1958, p. 65) tentatively correlated with the Hygiene sandstone member of the Pierre shale in northwestern Colorado crops out in sec. 28, T. 8 S., R. 68 W.

Paleontology: A few fragments of *Inoceramus* were found in a limestone in the upper part of the Pierre shale, and fragments of *Baculites* in the sandy shale equivalent (?) to the Hygiene sandstone.

Thickness: The thickness of the Pierre shale cannot be measured on the surface in this area because of poorly exposed contacts and extensive faulting. Two wells indicate a thickness of approximately 5500 feet. The J. S. Abercrombie No. 1 State well, in sec. 16, T. 8 S., R. 68 W., encountered 5440 feet of Pierre shale; and the F. G. Holl No. 1 Greenland Land and Cattle Co., well penetrated 5530 feet of Pierre shale.

Nature of contacts: The contact between the Pierre shale and the underlying Niobrara formation is believed to be an unconformity by LeRoy and Schieltz (1958), although earlier LeRoy (1946, p. 79-81) reported it to be lithologically transitional. The contact between the Pierre shale and the Fox Hills sandstone is transitional.

Environment of deposition: The Pierre shale was deposited in shallow marine waters at a moderate distance from shore. During deposition of the lower Pierre shales, circulation was restricted and the oxygen content of the water low (LeRoy and Schieltz, 1958, p. 2462).

Age and correlation: The Pierre shale has been assigned an Upper Cretaceous age on the basis of its fauna. It is correlated with the Mesa Verde group of the San Juan Basin in New Mexico, and with the Bearpaw shale, Judith River formation, Claggett shale, Eagle sandstone, and Telegraph Creek formation in Montana (Weimer, 1960).

Fox Hills sandstone

Nomenclature: The Fox Hills sandstone was named by Meek and Hayden (1861, p. 419, 427) to apply to the Formation No. 5 of the Cretaceous near the Fox Hills, Nebraska Territory. The name was generally used for the upper sandy shale and sandstone series of the Montana group, but inconsistent usage by different geologists led the American Association of Petroleum Geologists to appoint a committee to study the problem. They (Lovering and others, 1932, p. 702-703) redefined the Fox Hills as follows:

> The base of the Fox Hills formation shall be considered as the horizon below which the section is predominantly gray marine clay shales and sandy shales of Pierre age, and above which the section changes rapidly to a buff to brown sandstone containing numerous large gray to brown, hard, sandy concretions. This lower concretionary member is commonly overlain by a series of light gray to brown sandstones and sandy shales.
>
> The top of the Fox Hills formation shall be considered as the horizon above which the section is composed predominantly of fresh- and brackish-water deposits accompanied by coals and lignitic shales, and below which it is predominantly marine.

Lithology: The lower 55 feet of the Fox Hills sandstone is massive, brown, friable, fine-grained, limonitic sandstone. Above it is 25 feet of soft, tan, thin-bedded, very fine-grained quartz sandstone interbedded with some thin, light-gray shales and brown, thin-bedded calcareous siltstone.

Paleontology: No fossils were observed in the Fox-Hills sandstone, but Eldridge (Emmons, Cross, and Eldridge, 1896, p. 72) reported a molluscan fauna in this formation in the Denver Basin.

Thickness: The Fox Hills sandstone, as redefined by Lovering and others (1932, p. 702-703) is 80 feet thick in the Devils Head quadrangle.

Nature of contacts: The Fox Hills-Pierre contact is gradational, and has been placed according to the definition of Lovering and others (1932, p. 702-703). Their definition indicates the Fox Hills-Laramie contact may also be gradational, but in this area there is a sharp contact, with a light-gray, massive sandstone of the basal Laramie resting on brown, thin-bedded Fox Hills sandstone.

Environment of deposition: The Fox Hills sandstone, deposited in shallow marine or brackish waters, represents the last stage of marine sedimentation in the Foothills region.

Age and correlation: The Fox Hills sandstone is of Upper Cretaceous age as indicated by its fauna. It has been correlated with the Trinidad sandstone in southeastern Colorado and southeastern New Mexico, and with the Pictured Cliffs sandstone of southwestern Colorado and northwestern New Mexico (Heaton, 1950, p. 1560), although Weimer (1960, p. 5) placed it above those formations.

Laramie formation

Nomenclature: The name Laramie formation first appeared on maps by King (1876) and in a report by Hayden (1876, p. 20-27, 40-46). The name was loosely applied to rocks of varied ages over a wide area, and in 1910 the U. S. Geological Survey restricted it to the Denver basin (Wilmarth, 1938, p. 1151). The Laramie formation includes those strata between the top of the Fox Hills sandstone and the conglomeratic rocks that form the base of the Arapahoe-Denver and Dawson formations.

Lithology: The Laramie formation comprises a series of interbedded sandstones, siltstones, clays, carbonaceous shales, and occasional coal lenses. Exposures in the Devils Head quadrangle are generally poor and discontinuous. The basal portion is a massive to crossbedded gray fine-grained quartz sandstone, overlain by lenticular, irregularly bedded, light-gray to buff, fine-grained argillaceous sandstone. The upper part of the formation, almost entirely covered, appears to consist of similar light-gray to buff sandstones and siltstones, along with light-gray clays and dark gray to black shale.

Paleontology: Unidentifiable plant remains and silicified wood were the only fossils found in the Laramie formation in this area. Fossil plants have been found abundantly in the formation, particularly at Golden (Knowlton, 1896), and fossil dinosaurs from this formation in the Denver Basin were reported by Marsh (1896, p. 477).

Thickness: The Laramie formation is about 600 feet thick in this area.

Nature of contacts: The contact between the Laramie formation and the Fox Hills sandstone is lithologically distinct in this area, although the statement of Lovering and others (1932, p. 702-703) implies that this contact is generally gradational in this region. The contact between the Laramie formation and the Dawson arkose is lithologically distinct, although no discordance in attitude was noted. North of Jackson Creek, the Dawson arkose rests on Pierre shale, indicating an erosional disconformity below the Dawson. The erosional disconformity between the Laramie formation and the Arapahoe-Denver formation, equivalent to the Dawson, was recognized by Brown (1943, p. 84).

Environment of deposition: The strata of the Laramie formation are of continental origin, probably deposited on low plains dotted with lakes and swamps. The flora, reported by Knowlton (1896, p. 472), indicates a mild, warm climate.

Age and correlation: Its flora and fauna indicate that the Laramie formation is of Upper Cretaceous age. It is correlated with the Lance formation of northwestern Colorado, Wyoming, and western Montana, and with the Hell Creek formation of eastern Montana (Weimer, 1960).

Mesozoic - Cenozoic

The boundary between the Mesozoic and Cenozoic eras lies within the Dawson arkose. Dinosaur bones have been found in the lower part of the Dawson, and Tertiary vertebrate remains have been found at higher horizons, but the exact position of the time boundary has not been fixed.

Cretaceous - Tertiary

Dawson arkose

Nomenclature: The Dawson arkose was named by Richardson (1912), who applied the term to the lower member of Hayden's Monument Creek group. The name is derived from Dawson Butte which lies about three miles east of the Devils Head quadrangle.

Lithology: The Dawson arkose is a series of light-brown to buff, poorly bedded and cross-bedded, coarse- to very coarse-grained arkoses and conglomerates. Lenses of siltstone and micaceous shale are scattered through the section, particularly in the upper part. The base of the formation is characterized by an arkosic conglomerate containing pebbles and small cobbles of quartz, chert, quartzite, and granite. The top of the formation, including the Douglas rhyolite member, is not present in the Devils Head quadrangle, although a few fragments of rhyolite float, presumably transported by man, were encountered.

Bauer (1958, p. 73) divided the Dawson arkose into an upper and lower member, based on the relatively greater abundance of siltstone and shale in the upper member. He stated the boundary could be recognized in electric well logs but that it was very difficult to map on the surface. The division of the Dawson into two members is not used in this report.

Paleontology: No fossils were found in the Dawson arkose during this study, although vertebrate and plant fossils have been found in the Denver basin and east of Colorado Springs.

Thickness: The top of the Dawson arkose does not occur in the Devils Head quadrangle, so its original thickness is unknown. A well, the J. S. Abercrombie No. 1 State, in sec. 16, T. 8 S., R. 67 W., encountered 2700 feet of Dawson beds. It is estimated that about 2000 feet of Dawson arkose is left in the Devils Head quadrangle.

Nature of contacts: There is an erosional disconformity at the base of the Dawson arkose, which rests upon the Pierre shale just north of Jackson Creek, and upon the

Laramie formation south of Jackson Creek and in the northeast corner of the mapped area. The upper contact of the Dawson arkose, not found within the mapped area, was reported by Richardson (1912) to be an unconformity. There are local unconformities within the Dawson (Richardson, 1912; Bauer, 1958, p. 74) but of probable small extent (G. R. Scott, oral communication).

Environment of deposition: The lower part of the Dawson arkose is of Upper Cretaceous age as indicated by dinosaur remains, and the upper part has been dated as Eocene on the basis of vertebrate fossils (Wilmarth, 1938, p. 575-576), but the exact horizon of the time boundary has not been fixed. The Cretaceous part of the Dawson arkose interfingers with the Arapahoe formation and with the lower part of the Denver formation. The Tertiary part of the Dawson arkose is correlated with the upper Denver formation.

METAMORPHIC AND IGNEOUS ROCKS

The so-called crystalline rocks of the Devils Head area comprise schists, gneisses, and migmatites of the Idaho Springs formation; Pikes Peak granite, with its associated aplites and pegmatites; and diabasic andesite dikes. The diabase dikes are probably of Tertiary age; the other crystalline rocks are of Precambrian age.

Idaho Springs formation

The Idaho Springs formation was named by Ball (1906, p. 374) from its typical exposure near Idaho Springs, Colorado. He considered the rocks to be metamorphosed sediments and recognized four general rock types: biotite-sillimanite schist, biotite schist, quartz gneiss, and lime silicate rocks. The formation name has since been applied by other writers to most of the metamorphic rocks in the Front Range. Recent work by geologists of the U. S. Geological Survey in various parts of the Front Range (Drake, 1957; Harrison and Wells, 1956, 1959; Sims and others, 1955, 1958) has disclosed a much greater variety of rock types and has demonstrated the possibility of mapping lithologic units within the Idaho Springs in different places. Close correlation of units over large distances is questionable, although such correlations have been attempted (Boos, 1960).

Within the Devils Head quadrangle, Idaho Springs rocks occur only in the NW$\frac{1}{4}$ sec. 9, T. 8 S., R. 69 W. The metamorphic rocks along the edge of the batholith in the southern part of the Kassler quadrangle were also mapped during this investigation.

Because only a narrow strip of metamorphic rocks was examined, and because outcrops are scattered, the Idaho Springs formation was mapped as an undifferentiated unit. Samples of the principal rock types were collected and examined; the results are summarized in Table 1. In the order in which they appear in the table, the rock names are biotite-cordierite-orthoclase-andesine-quartz gneiss; augite-labradorite-quartz gneiss; chlorite-biotite-bytownite-quartz schist; biotite-microcline-quartz gneiss; sillimanite-microcline-quartz hornfels; sericitized biotite-andesine-quartz schist;quartz-labradorite-hornblende gneiss (amphibolite); quartz-microcline hornfels (migmatite); biotite-andesine-microcline-quartz schist; and sericite-quartz-hornblende schist.

These are all high-grade metamorphic rocks. The first two are assigned to the pyroxene hornfels metamorphic facies;

Table 1. Approximate modes of metamorphic rocks from the Devils Head area.

Sample No.	1	2	3	4	5	6	8	9	11	12	13	19
Quartz	72	46	63	35	78	65	50	65	15	30	40	20
Microcline	Tr			30	2	22	33			70	30	
Orthoclase	5											
Plagioclase	15	25	25	25		3		20	25	Tr	20	
Biotite	3		10	10	15	10	2	5			5	
Hornblende									60			65
Sillimanite							15				3	
Augite		25										
Cordierite	5										1	
Magnetite	Tr	1	1	Tr	1	Tr	Tr	Tr	Tr		1	Tr
Clinozoisite		1										
Epidote		1										
Sericite	Tr	Tr	Tr	Tr	Tr	Tr	Tr	10	Tr	Tr		12
Muscovite	Tr			Tr	4		Tr	Tr		Tr		
Chlorite		Tr	1	Tr	Tr	Tr	Tr	Tr				3
Sphene		1	Tr							Tr		Tr
Zircon	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr		Tr
Apatite		Tr	Tr		Tr	Tr		Tr	Tr	Tr		Tr
Pyrite									Tr			
Hematite				Tr								Tr
Limonite											Tr	

the others are assigned to the almandine amphibolite facies (Turner, 1958). The mineralogy indicates that the parent rocks belonged to the pelitic and the quartzo-feldspathic chemical classes, consistent with an original sedimentary deposition of the Idaho Springs formation.

According to Lovering (1929), the Idaho Springs formation was laid down as a series of marine sandstones and shales. Tectonism 1500 million years ago (Giffin and Kulp, 1960) caused high-grade regional metamorphism of the formation and developed the almandine amphibolite facies in the Devils Head area. Intrusion of the Pikes Peak batholith about 1050 million years ago produced the higher-grade pyroxene hornfels facies in the walls immediately adjacent to the contact.

Pikes Peak granite

Pikes Peak granite underlies all of the Devils Head quadrangle except the extreme northwest corner and a mile-wide strip along the eastern edge. On the east, the granite is bounded by high-angle thrust faults, so the original eastern extent of the granite is unknown. On the north, in the southern part of the Kassler quadrangle, the granite is in intrusive contact with the Idaho Springs formation.

Petrography

The Pikes Peak granite in the Devils Head quadrangle is pink to pale pinkish-gray, coarse-grained (Travis, 1955, p. 3) hornblende-bearing biotite granite, quartz monzonite, and leucogranite. It weathers differentially to give exfoliation domes and shells, isolated and relict boulders, and in places thick deposits of a gravelly rubble called grus (Stokes and Varnes, 1955, p. 68). Near the eastern edge, where the granite has been extensively sheared along with the thrust faulting, the granite is heavily stained by hematite, so it is brick red to reddish brown. This stain is very noticeable as one approaches the mountain front from the east.

The granite is holocrystalline, equigranular to somewhat seriate inequigranular, coarse-grained, hypidiomorphic granular. Perthitic texture abounds, myrmekitic texture is common, and some antiperthic texture occurs. The minerals of the granite are quartz, microcline, and plagioclase, with smaller amounts of biotite and hornblende, and accessory magnetite, allanite, fluorite, sphene, zircon, and apatite. As the proportions of the minerals change from place to place within the batholith, the classification of the rock, following the system of Johannsen (1931) or of Travis (1955), changes from granite to quartz monzonite to leucogranite.

The quartz is generally anhedral, and shows well-developed linear to irregular bubble trails and scattered minute rutile needles. The microcline shows prominent grid twinning, and perthitic structure which varies from grain to grain and from section to section.

Several different varieties of plagioclase may be found in the same section. Subhedral, distinctly zoned crystals are believed to be primary plagioclase; they range from An_{27} to An_{41} in composition. Subhedral to anhedral, generally unzoned crystals, An_{25} to An_{34}, probably represent exsolution and recrystallization.

Around the edges of some of the feldspar grains, particularly where microcline is in contact with plagioclase, clear and sometimes untwinned albite, about An_7 to An_{10}, is common. It is believed to represent albite exsolved from microcline during cooling. In some specimens the feldspars are strongly sericitized.

Biotite occurs as greenish-brown anhedral flakes with marked pleochroic haloes around included tiny euhedral zircon crystals. In a few sections, uncommon grains of bright breen biotite were found; they appear to have formed later than the brown biotite. Hornblende occurs as pleochroic green subhedral to anhedral crystals. The biotite and hornblende are partly altered to chlorite in some sections.

Allanite is a ubiquitous accessory mineral, generally as rounded subhedral grains. It is often optically isotropic (metamict) and is surrounded by radial and concentric fractures in the enclosing minerals. Purplish to colorless fluorite occurs as irregular interstitial grains. Magnetite occurs as anhedral grains altering to hematite in places. Apatite occurs as tiny euhedral crystals. In some specimens there is a strong tendency for the mafic minerals and the accessories to be clustered together.

Along the Rampart Range road in the SW$\frac{1}{4}$ sec. 23, T. 8 S., R. 69 W., a plug of hydrothermally altered granite is exposed in the east wall of the road cut. The plug occupies an elliptical area east of the road about 100 yards from north to south and 200 yards from east to west. Surface exposures are poor, and the boundary cannot be sharply delineated.

No trace of the alteration zone was found in the west bank of the road cut. In the east bank, the zone seems to be tapering slightly downward. The granite in the alteration zone was changed to lavender or light gray with scattered dark red hematite, and shows distinctly as one drives past on the road.

The alteration removed the mafic minerals from the granite, and highly sericitized and argillized the feldspars. The clay is believed to be largely montmorillonite, as samples of the altered granite swell and break up in water. Specular and earthy red hematite has been added to the rock. In some specimens quartz appears to have been removed; in others, authigenic quartz encloses dusty clay phantoms.

Structural controls, such as faults or major joints, of the alteration zone are not apparent. The altering fluids are believed related to the andesite dikes; a narrow border of similar altered granite was seen in the fault zone adjacent to the dikes in some places. The sharp contacts of this zone and the absence of such alteration at the surface elsewhere are evidence against deuteric alteration or surficial weathering.

Modal and chemical analyses

Because of the coarse grain of the granites, several standard thin sections of each sample were required for modal analysis. Following Chayes (1956, p. 79-85) it was determined that five sections for each sample would give good accuracy within a reasonable counting time. A series of samples from different localities in the quadrangle was counted using the Chayes point counter. The modes calculated from these counts are presented in table 2.

Two samples of granite, one of aplite, and one of andesite were submitted to Dr. H. B. Wiik of Helsingfors, Finland, for chemical analysis. His analyses are presented in table 3, and CIPW norms calculated by the writer from those analyses are shown in table 4. The norms for the granites and aplite agree very well with the modes (table 2), but the norm of the andesite differs appreciably from its mode.

Petrology

Analytical results.

Chemical and microscopic analyses were made on Pikes Peak granite, and X-ray analyses were made

Table 2. Modal composition of igneous rocks from the Devils Head quadrangle

Sample No.	21*	22	25*	26	28	30	31	32	34	41*	51*	52
Quartz	30.7	33.2	25.6	24.4	28.0	28.1	28.9	30.8	30.3	37.5	--	--
Microcline	48.1	42.6	52.4	55.1	39.6	53.9	36.2	47.9	38.3	44.8		
Plagioclase	17.1	17.1	18.8	14.2	24.0	13.0	26.8	17.8	21.7	11.5	66.8	53.1
Biotite	3.4	3.9	2.9	4.5	4.0	2.9	7.0	2.9	6.6	5.5	4.7	1.5
Hornblende		2.2		1.0	3.1	1.3	Tr	0.3	0.9			
Magnetite	0.3	0.5	0.2	0.2	0.3	0.4	0.1	0.1	0.8	0.5	7.0	8.1
Augite	--	--	--	--	--	--	--	--	--	--	18.9	35.7
Olivine	--	--	--	--	--	--	--	--	--	--	1.1	1.6
Apatite	Tr	0.2	Tr	0.1	0.2	0.1	Tr	Tr	0.1		0.9	Tr
Zircon	0.1	0.2	0.1	Tr	0.1	0.2	Tr	Tr	0.1	0.1	0.2	Tr
Fluorite	0.2	0.1	Tr	0.4	0.1	0.1	0.6	0.2	1.0			
Allanite	Tr	0.1	0.1	Tr	0.1	0.1	0.3	Tr	0.1	0.1		
Sphene		0.1		0.1	0.5	Tr		Tr	Tr		0.4	
Johannsen Symbol @	126'P	226'P	126'P	226'P	226"P	126'P	226"P	126"P	226"P	226'D	2212H	2212H

*For chemical analysis, see table 3.

@ 126'P = Leucogranite; 226'P = Granite; 226"P = Quartz monzonite; 226'D = Aplite; 2212H = Andesite

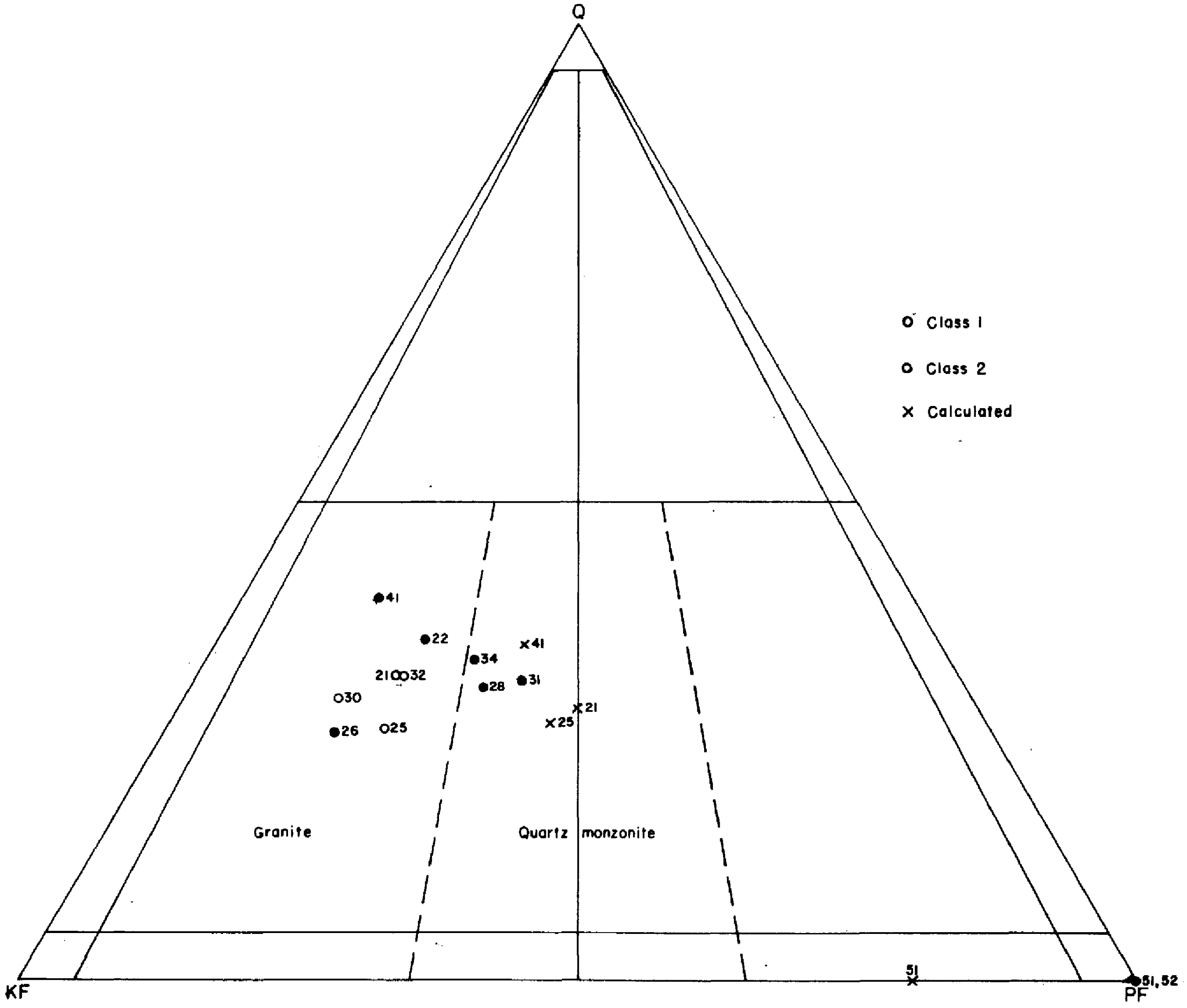

Figure 3. Modes of rocks of the Devils Head quadrangle plotted on a Johannsen classification diagram.

Table 3. Chemical Analyses, in Weight Percent, of Rocks from the Devils Head Quadrangle. (Dr. H. B. Wiik, analyst, February, 1961)

Sample number	21 Leucogranite	25 Leucogranite	41 Aplite	51 Diabase
SiO_2	71.64	70.85	74.77	45.21
Al_2O_3	13.93	14.49	12.38	14.43
Fe_2O_3	0.92	1.03	1.18	6.50
FeO	1.36	1.44	1.22	8.90
MgO	0.27	0.24	0.21	6.71
CaO	1.09	1.19	0.73	6.64
Na_2O	3.54	3.22	2.83	3.18
K_2O	5.69	6.18	5.98	2.00
TiO_2	0.26	0.30	0.20	2.63
P_2O_5	0.12	0.12	0.03	0.54
MnO	0.06	0.06	0.05	0.23
CO_2	0.00	0.00	0.00	0.00
Cl	0.02	0.02	0.02	0.01
F	0.15	0.12	0.18	0.04
Rb_2O	0.04	0.04	0.04	0.03
H_2O+	0.35	0.62	0.36	2.23
H_2O-	0.09	0.07	0.06	0.14
	99.53	99.99	100.24	99.42
Less O for F & Cl	0.06	0.05	0.07	0.02
	99.47	99.94	100.17	99.40*

*Does not include a little S, not determined.

Table 4. CIPW Norms of Rocks of Devils Head Quadrangle

Normative mineral	Weight percent			
Sample number	21	25	41	51
Quartz	26.46	25.32	33.48	
Corundum	0.41	0.71	0.20	
Orthoclase	33.92	36.70	35.58	11.68
Albite	29.87	27.25	23.58	27.25
Anorthite	3.89	4.73	3.06	18.90
Diopside				8.50
Hypersthene	2.02	2.05	1.42	2.69
Olivine				12.28
Magnetite	1.39	1.39	1.86	9.51
Ilmenite	0.61	0.61	0.46	5.02
Apatite	0.34	0.34		1.34
Fluorite	0.31	0.23	0.39	
CIPW symbol. . .	I.4.2.3.	I.4.2.3.	I.4.1.3.	III.5.3.4.

on selected feldspars from the granite; the results of these analyses lead to some possible petrologic conclusions.

The chemical analyses of two granites and an aplite, when calculated as norms, give orthoclase-albite-quartz ratios near 1:1:1. This is approximately the lowest-melting composition found by Tuttle and Bowen (1958, p. 54-75) for the system albite-orthoclase-quartz-water, and is interpreted as evidence for a magmatic origin of the granite.

The soda-lime-potash ratios are such that according to Tuttle (1952, p. 116-120) all the plagioclase should have formed by unmixing from anorthoclase, unless fluxing by volatiles had lowered the liquids enough to permit two feldspars to crystallize simultaneously. The work of Tuttle and Wyllie (1957) and the presence of appreciable amounts of fluorite in the granite suggest a possible source of fluxes, and the presence of apparently primary plagioclase indicates that fluxing actually occurred.

X-ray studies on the feldspars, discussed in a later section, show that unmixing of plagioclase from microcline also took place. The final temperature of unmixing was relatively low and uniform throughout the area.

Modal analyses of different samples of the granitic rocks differ enough to justify different rock names (Travis, 1955; Johannsen, 1931), but the differences are not very great, and are so gradational that no systematic zoning of rock types is indicated. It is inferred that the differences in composition do not represent definite zoning in the granite, but rather local inhomogeneities of the magma. Digestion of xenoliths might cause such local changes in composition.

If the classification of Tuttle and Bowen (1958, p. 129-130) were used, the rocks would all be classed as subsolvus granites.

Origin of the granite. Although treated separately here, the origin of the granite and its emplacement are related problems that cannot be completely separated.

The definite contact between the granite and the metamorphic wall rocks, the absence of contamination in the granite near the contact, and the composition of the granite near the quartz-orthoclase-albite cotectic (Tuttle and Bowen, 1958) indicate the origin of the granite as magma, rather than by "granitization". The granitic magma may have resulted (1) by differentiation from a more basic magma (2) melting of sialic material by intrusion of basic magma at depth followed by rise and reintrusion of granitic magma at higher levels, or (3) selective remelting of rock material at depth followed by rise of granite magma (Hutchinson, 1960).

The third hypothesis is believed to be the most probable explanation. During the deformation 1500 million years ago (Giffin and Kulp, 1960) that caused the regional metamorphism of the Idaho Springs formation, strong downfolding in the area of the Pikes Peak batholith may have carried Idaho Springs and underlying rocks to depths of several miles. At the temperatures prevailing at these depths and in the presence of water and other volatiles, melting of some of the minerals of these rocks would give rise to a liquid of granitic composition (Tuttle and Bowen, 1958, p. 121-124). At deeper levels more basic compositions would be liquid, and differentiation of those liquids would add to the volume of granite. As large volumes of granite were formed, they would tend to rise to levels of lower pressure and temperature and would crystallize later as intrusive granite. Hutchinson (1956, 1960b) explained the formation of the Enchanted Rock batholith in Texas by this mechanism.

Basic fractions of the differentiated liquid and/or unmelted basic refractory minerals from the partially remelted rocks would accumulate at depth, and might afford an explanation of the positive gravity anomaly that Qureshy (1958) found over the Pikes Peak batholith.

Emplacement of the granite. It is believed the granite was emplaced by forcible intrusion of an upward-moving liquid. The mode of origin postulated above fits this view, and the steeply dipping platy flow structure found by Hutchinson (1958b, 1960a) in the Pikes Peak granite a few miles west of the Devils Head quadrangle supports the conclusion. In the Devils Head quadrangle, platy flow structure is too weakly developed to be distinguished consistently, but in a few places a more or less vertical platy flow structure was discerned.

General concordance of the foliation in the wall rock to the granite contact, particularly where the foliation swings sharply near the contact to a conformable attitude; and bulging outward of the granite over the wall rocks (Hutchinson, 1958b) are taken to indicate forcible intrusion. There is no evidence for block foundering, and the general absence of xenoliths along the contact, and within the batholith, is inconsistent with piecemeal stoping.

Room for intrusion was made partly by crowding aside of the wall rocks, but mostly, it is believed, by uplift of the overlying cover, which has since been eroded away.

The granite was probably emplaced in the mesozone as defined by Buddington (1958, p. 676). The structural relationships outlined above accord with his criteria. Buddington (1958) believes most intrusives in the mesozone are post-tectonic. The ages of just over 1000 million years (Hutchinson, 1959a; Giffin and Kulp, 1960) for the Pikes Peak granite and about 1500 million years for the tectonism in this region (Giffin and Kulp, 1960) show that this is indeed the case for the Pikes Peak batholith.

Aplites

Many aplites are scattered through the Devils Head quadrangle, particularly in the southwest corner where aplites and pegmatites are abnormally abundant. This area of high concentration of aplites and pegmatites extends south and west some distance into the adjoining quadrangles.

Except for three large aplite bodies in sec. 16, T. 9 S., R. 69 W., the aplites are relatively small. They occur as rounded pods a few inches to a few feet in diameter; as flat-lying rod-shaped bodies, of circular or elliptical cross-section, up to 50 feet long and 5 feet in diameter; as gently to steeply dipping lenses a few inches to a few feet thick and up to a few tens of feet long; and in a few cases as distinct dikes a few inches to a few feet wide and up to a few tens of feet long. The large aplites are lenticular bodies up to 50 yards wide and 300 yards long.

Although attitudes of the aplites are quite varied, there is a distinct prevalence of northwesterly trends. If the north-trending faults in the area are interpreted as shears resulting from a generally northwest-southeast compression, the northwest trend might be explained as due incipient tension in a northeast-southwest direction. It is felt, however, that many of the aplites formed while the granite was still too plastic to transmit much stress, particularly in tension.

The relation between the aplites and the enclosing granite is varied. In places the contact between granite and aplite is sharp and distinct, but more commonly the contact is gradational over a few inches. A number of aplites have cores of apparently normal granite, or of pegmatite; others have pegmatitic material along the walls; and still others seem to be random mixtures of aplite, granite, and pegmatites. Small miarolitic cavities are found in many of the aplites.

Petrographically, most of the aplites are holocrystalline, equigranular, fine-grained, allotriomorphic-granular. They consist of quartz, microcline, oligoclase, and accessory biotite, magnetite, allanite, apatite, fluorite, and zircon. A few aplites are porphyritic, with 5 to 10 mm phenocrysts of microcline in a groundmass of normal aplite. Most of the aplites contain few dark minerals, but a few contain five percent or more biotite. In some of the aplites this biotite occurs as thin lenticular streaks parallel to the walls of the aplite.

A sample of biotitic aplite from the west flank of Devils Head was analyzed chemically; the results are shown in table 3. The norm calculated from this analysis is shown in table 4, and the mode of the rock in table 2.

The chemical analysis of the aplite is quite similar to those of the granite. This fact, along with the close and varied relationship between the granite, aplite, and pegmatite, suggests that these rocks all crystallized from the same liquid and nearly contemporaneously. Most of the aplites probably represent segregation pockets of the last magma to crystallize, although some may represent residual magma injected along tension fractures. The abundance of aplites and pegmatites in the southwest corner of the quadrangle probably indicates that the area was one of the last parts of the batholith to solidify, thereby permitting the accumulation of many pockets of residual magma that formed the aplites and pegmatites.

Pegmatites

The pegmatites of the Devils Head quadrangle are here divided arbitrarily into two classes, large and small. The large pegmatites are defined as those large enough to have been mined; all others are defined as small pegmatites. This size distinction holds well, as no unmined pegmatite large enough for exploitation was found.

The small pegmatites are mineralogically simple, consisting of quartz, microcline, a little albite, occasional biotite, and in a few cases trace amounts of allanite, samarskite, and fergusonite. Average grain size is from 2 to 4 inches. The sizes, shapes, attitudes, distribution, and probable origin of the small pegmatites is so similar to those of the aplites described above that these descriptions may be taken for the small pegmatites also. The close relationship between granite, aplite, and pegmatite has been described above; some of the bodies could be classed equally well as aplite or pegmatite.

There are several of the large pegmatites in the southern half of the Devils Head quadrangle. Five are near the Devils Head campground in the NW$\frac{1}{4}$ sec. 15, and the SW$\frac{1}{4}$ sec. 10, T. 9 S., R. 69 W. Two are close together in the SE$\frac{1}{4}$ sec. 1, and the NE$\frac{1}{4}$ sec. 12, T. 9 S., R. 69 W. Others are in the NW$\frac{1}{4}$ sec. 35, T. 8 S., R. 69 W; the NE$\frac{1}{4}$ sec. 18, T. 9 S., R. 68 W.; and the NE$\frac{1}{4}$ sec. 21, T. 9 S., R. 69 W.

All these pegmatites except the last mentioned, commonly known as the Devils Head pegmatite, have been mined for feldspar. They are circular or elliptical in plan and from about 50 to 250 feet in greatest dimension. The largest pegmatite, in the NE$\frac{1}{4}$ sec. 12, T. 9 S., R. 69 W., is exposed for 60 feet vertically; the others, for lesser distances. In no case has mining exposed the bottom of the pegmatite. None of the mines has been active during this investigation.

The contacts with the normal granite in the walls are gradational over a few inches. Little or no structural orientation appears in the pegmatites, and zoning is weak or absent. The minerals of the pegmatites comprise quartz, microcline, albite, and a little biotite; no fluorite, topaz, or rare-earth or radioactive minerals were found. Feldspar crystals in the pegmatites range up to about two feet across. Large irregular pods of quartz are scattered through the feldspar so that much hand cobbing was required for mining.

The elliptical plans, the gradational walls, and the lack of structural orientation suggest that these pegmatites originated as segregation pockets of residual magma, rather than as dikes of injected magma. They are probably contemporaneous with the small pegmatites and the aplites.

The Devils Head pegmatite has been often mentioned in the literature (R. T. Cross, 1883; Whitman Cross, 1884; Eakins, 1886; Hanley, Heinrich, and Page, 1950; Hillebrand, 1888; Landes, 1935; Peacock, 1935; Pearl, 1941, 1951; Smith, 1885, 1887) although usually for the minerals that occurred there rather than to describe the pegmatite. The pegmatite has been completely mined out and none of the rock is now in place. All that is now left is a shallow open-cut about 80 feet long and 10 feet wide.

According to Smith (1885) the pegmatite was a large miarolitic cavity about 50 feet long, 2 to 15 feet wide and 4 feet deep. It contained notable topaz crystals along with quartz, microcline, albite, muscovite?, cassiterite, goethite, allanite, fluorite, and kaolinite. Manganite, gadolinite, samarskite, and hematite have also been found. According to Peacock (1935), there was a series of pockets or miarolitic cavities along the pegmatite.

The remnants of the deposit are now held as mining claims by the Colorado Mineral Society to preserve it for mineral collectors.

Andesite Dikes

A series of andesite dikes was found in the Devils Head quadrangle, scattered at intervals along the Pine Creek-Bear Creek fault from the southern part of sec. 16, T. 8 S., R. 69 W., to the middle of sec. 9, T. 8 S., R. 69 W., and along the Jackson Creek-South Garber Creek fault from the middle of sec. 13, T. 9 S., R. 68 W., to the middle of sec. 18, T. 8 S., R. 68 W.

Individual dikes range in width from a few inches to about 20 feet, and in the exposed length from a few feet to perhaps 1000 feet. All the dikes are covered by soil or slope wash at their ends, so the true lengths cannot be determined. Dips are steep, ranging from vertical to about 60°W. Near the north edge of sec. 16, T. 8 N., R. 69 W., along Colorado Highway 67, a quartzite dike has been intruded by one of these andesite dikes. Narrow chill borders may be seen on some of the dikes.

The rock of the dikes is dark green to black, holocrystalline, aphanitic to porphyritic aphanitic with a generally subophitic texture. The minerals comprise subhedral, tabular andesine that ranges in composition from An_{34} to An_{48} in different dikes; subhedral augite; anhedral to subhedral olivine; accessory subhedral to anhedral biotite, magnetite and sphene;

and accessory euhedral apatite and zircon. The olivine and biotite have been partially chloritized and the augite has been uralitized and chloritized. Magnetite is altered to hematite and limonite, and the plagioclase is strongly sericitized.

The porphyritic phases of the rock contain 1/16- to 1/4-inch phenocrysts of andesine in an aphanitic groundmass of plagioclase and mafic minerals. Near the walls of the dikes the tabular phenocrysts tend to be oriented parallel to the walls.

The dikes were intruded along old fault zones, probably during renewed movement. No dikes were found intruding either the sedimentary or the metamorphic rocks in the Devils Head area, but Peterson and Scott (1960) reported similar dikes in the metamorphic rocks of the Platte Canyon and Kassler quadrangles. The andesite dikes are later than the sandstone dikes of probable Upper Cambrian age, and earlier than the latest faulting in the area, because some of the dikes are cut by faults. The dikes are inferred to be of Tertiary age by analogy with the andesitic rocks of the Denver Basin. The dikes may correlate with the Buffalo Peaks andesite in the South Park area (Gould, 1935, p. 972).

Although the writer found discontinuous outcrops of the dikes, in places en echelon, along the Jackson Creek-South Garber Creek fault zone, R. F. Bublitz (oral communication) found an apparently continuous zone of high magnetism throughout much of the length of the fault. It is inferred that the scattered surface outcrops represent high points on a dike that is continuous at depth. If it is surmised that the dikes are fed by a large mass of mafic rock at depth, a logical explanation is afforded for the positive gravity found by Qureshy (1958) in this region.

Feldspar Studies

An investigation of feldspars from the granites of the Devils Head quadrangle was undertaken to develop more petrologic information about the granite and pegmatites. In recent years many techniques for studying feldspars have been employed: chemical and kinetic studies (Bowen and Tuttle, 1950; Goldsmith, 1952; Laves, 1952; McConnell and McKie, 1960; Schairer, 1950; Tuttle and Bowen, 1958); X-ray powder methods (MacKenzie, 1957; Orville, 1960; Smith and Yoder, 1956; Smith, 1956; Tuttle and Bowen, 1950); X-ray single-crystal methods (Cole and others, 1949, 1951; Ferguson, Traill, and Taylor, 1958; Gay, 1956; Laves, 1950; Laves and Chaisson, 1950; MacKenzie and Smith, 1955, 1956; Megaw, 1959; Smith and MacKenzie, 1955); optical methods (Foster, 1955; Laves and Chaisson, 1950; MacKenzie and Smith, 1956; Tuttle and Bowen, 1950); infrared spectroscopy (Thompson and Wadsworth, 1957). From the varied, and sometimes conflicting, data reported by various workers, it is apparent that the feldspars are still poorly known. Because of limited time and facilities, the writer's investigation was confined to a reconnaissance study of a few feldspars by X-ray powder methods. It was felt that this reconnaissance study might yield some usable data in addition to pointing the way for further work.

Eight samples were selected. Six of these were of microcline from granite, selected for both compositional and geographical differences, and the other two were an albite and a microcline from the Colorado Mineral Society pegmatite at Devils Head. The pegmatitic microcline was part of a larger crystal; the albite was part of a bladed mass of cleavelandite. The microcline from the granites was obtained by hand picking under a lens from rock crushed to minus 35 mesh. The selected samples, 7 to 10 grams each, were pulverized to about minus 200 mesh in a Braun pulverizer equipped with alumina ceramic plates. A 1-gram cut was taken from each sample for X-ray study, and the rest was submitted for chemical analysis. Chemical analyses, performed by Mr. G. E. Manning under the direction of Dr. R. E. Bisque of the Chemistry Department, Colorado School of Mines, are shown in table .

X-ray specimens were prepared by grinding to -325 mesh in an agate mortar, mixing some of the powder with "Duco" cement to form a paste, and rolling between two glass plates in a jig to give a spindle 0.010 inches in diameter. The spindle was mounted in a powder camera 114.59 millimeters in diameter, and the diffraction pattern recorded on film using copper K_α radiation. For each sample a second spindle was made, with potassium bromate added as an internal standard, as recommended by Orville (1960).

The albite diffraction pattern could be indexed by using the information in the ASTM Powder Data File, but the file contained no indexed pattern for microcline. No indexed

Table 5. Chemical composition, in weight percent, of feldspars from the Devils Head quadrangle. (G. E. Manning, analyst, April 1961).

Sample No.	21	25	26	29	32	35	81	82
SiO_2	66.0	65.61	65.06	65.73	66.15	65.65	65.82	67.96
Al_2O_3	19.40	18.80	18.26	19.05	18.45	18.80	18.43	19.80
Fe_2O_3	. . . . Less than 0.2 %.							
CaO	0.90	1.03	1.30	1.26	1.25	1.09	0.47	0.35
MgO	0.14	0.29	0.34	0.29	0.15	0.01	0.00	0.18
Na_2O	2.41	1.91	3.19	3.17	3.30	3.16	0.64	11.30
K_2O	11.20	11.69	11.63	11.42	10.80	12.62	14.00	1.42
Total	100.05	99.33	99.76	100.92	100.10	101.33	99.36	101.01
$\frac{Or}{Or + Ab + An}$	71.1	75.0	65.5	65.4	63.4	68.2	90.8	7.4
$d_{\bar{2}01}$ Å	4.220	4.219	4.217	4.217	4.222	4.219	4.222	4.022

pattern for microcline was found in the literature. The microcline pattern was indexed by calculating the d-spacings for all possible indices on a microcline from Pikes Peak; the lattice parameters for this calculation were obtained from card number 2-253 of the ASTM Powder Data File. The calculations were made on an LGP-30 electronic digital computer from a program developed by the writer using the Act I Compiler system (Boswell, 1959).

Line positions on the diffraction patterns could be measured with a precision of about 0.1 mm, which corresponds to a precision in calculated d-spacings of about 0.019 Å for the $\bar{2}01$ reflection. Although not good enough for accurate determinations of composition after Bowen and Tuttle (1950, p. 493) or Orville (1960), the precision is good enough that chemical variations as great as indicated by the analyses (table 5) should be detected.

The values of d-spacing for the $\bar{2}01$ planes of each of the eight feldspars are shown in table 5. Each listed value is the average of two determinations on different patterns from the same sample. In all cases the difference between the two patterns was less than might be expected from the precision of measurement.

Within the limit of precision of measurement, the d-spacings for the microclines is the same, regardless of the chemical analysis. In each pattern of microcline from granite however, there appears next to the 111 line of microcline a faint extra line that corresponds to the $\bar{2}01$ line of albite. This line does not appear in the patterns of the pegmatitic microcline. In thin sections of the granite, much of the microcline is perthitic.

It appears obvious, therefore, that the "microclines" from the granite consist of two phases, microcline and albite. The microcline phase has essentially the same composition in all samples, and presumably the albite phase does likewise. The differences in analyses, therefore, are probably due to the relative amounts of exsolved albite within the microcline. This conclusion could not be checked by the microscope. The total variation in orthoclase/plagioclase ratio is not great, and the variation in perthitic texture from grain to grain even within the same thin section is so great that sufficiently extensive and accurate measurements to check the conclusion are impractical.

Presumably, if the perthitic microcline were homogenized by heating prior to taking the diffraction pattern, the $\bar{2}01$ spacing would vary with the analysis (and composition), but as pointed out by Tuttle and Bowen (1958, p. 11) such homogenization may take several weeks at 1050°C. Facilities for such treatment were not available to the writer. Samples of the albite and the pegmatitic microcline were heated for two days at 1050°C and air quenched. Their diffraction patterns showed no significant changes from those of unheated samples.

The present study shows that the feldspars of the granite unmixed after crystallization. The uniform values of d-spacing of the $\bar{2}01$ planes of the microclines indicate that the microcline phase in the granites are similar, and probably are close to the composition of the pegmatitic microcline. The studies of Bowen and Tuttle (1950) indicate that if the unmixed feldspars have similar compositions, they probably unmixed at similar temperatures. The final unmixing temperature must have been relatively low, because the pegmatitic microcline is green; green microcline probably cannot form above 270°C (Oftedal, 1957).

It is likely that further X-ray studies of the feldspars, using a diffractometer and a set of standards to determine accurately the compositions and relative amounts of the different phases, would yield petrologically significant information. Single-crystal studies along the lines of MacKenzie and Smith (1955, 1956) also appear promising. However, such studies, major problems in themselves, could not be considered for this investigation.

STRUCTURAL GEOLOGY

Regional Setting

The Devils Head quadrangle is in the transition zone between the Denver Basin and the Front Range massif, the two dominating structural units of central Colorado.

The Denver Basin is a large asymmetric syncline with a steeply dipping west limb and a more gently dipping east limb. Its axis trends northwest from southeastern Colorado to Denver and thence curves to the northeast (Plate 4). The axis plunges from both directions toward Denver, beneath which lies the deepest part of the basin.

Although sedimentation in the Denver Basin began in Early Paleozoic time, the major structural development is of Late Cretaceous age. Of some 15,000 feet of sedimentary rocks in the Denver Basin, more than 10,000 feet were deposited during the Late Cretaceous period.

The Front Range massif is a large block of predominantly Precambrian rocks bounded on the east and west by thrust faults (Badgley, 1960, p. 165). The boundary between the Front Range and the Denver Basin is a steep monoclinal fold, broken by thrusting along the Golden-Rampart Range fault system and by transverse normal faults.

Within the Front Range, foliation patterns and intrusive bodies outline two foliation salients that form an arcuate junction with accompanying shear zones (Badgley, 1960, p. 165). Badgley (p. 166) believes the foliation patterns result from Early Precambrian compressive folding accompanied by syntectonic catazonal intrusion of Kenosha and Boulder Creek plutons. Post-tectonic intrusion of Pikes Peak and Silver Plume granites probably occurred in the mesozone.

A second period of compression caused cataclastic deformation as well as folding. Faults developed in the granites and metamorphic rocks, and a pattern of lineations was superimposed on that developed earlier (Harrison and Wells, 1956, 1959: Sims and others, 1955, 1958).

Early Paleozoic faulting, probably largely along earlier Precambrian fault lines, resulted in the formation of the sandstone dikes.

Igneous activity during Tertiary time resulted in the emplacing of dikes, plugs, and stocks, and the accumulation of volcanic rocks in a number of areas. In the Devils Head area, the dikes largely followed earlier faults.

Strong east-west compression developed thrust faults on the east and west sides of the Front Range massif, as well as conjugate shears within the block. The high angle of the thrusts in many places indicates a pronounced vertical component along with the east-west compression. Many of the Laramide faults represent renewed movement along earlier faults, some of them dating back to Precambrian. Northeast-trending normal faults in the Devils Head area probably represent movement in the northeast shear direction mentioned by Lovering and Goddard (1950, p. 58).

Regional uplift and erosion subsequent to the Laramide deformation have resulted in the present physiographic development of the region.

Local Structure

Local structural features in the Devils Head area include foliation and lineation within the metamorphic rocks; the contact between the granite and the metamorphic wall rocks; several prominent north-trending faults in the granite; steep monoclinal folding and high-angle reverse faulting or thrusting along the boundary between the Front Range and the Denver Basin; a series of northeast-trending cross faults in this boundary zone; and an area-wide joint system within the granite.

Foliation and lineation in metamorphic rocks

Structures within the metamorphic rocks were not studied in detail, because the area of metamorphic rocks in the Devils

Head quadrangle is small and poorly exposed and because the rocks in the Kassler quadrangle have already been mapped by Glenn R. Scott of the U. S. Geological Survey (publication in preparation). Observations were made on the wall rocks near the granite contact in the Kassler quadrangle.

Strike and dip of foliation within the metamorphic rocks varies markedly within short distances, sometimes a few feet, because of the many minor warps and folds within the rocks. There is a distinct predominance, however, of west-northwesterly strikes and northerly dips of the order of 60 degrees. Similarly, lineations, represented by mineral streaks, drag fold axes and crinkles in foliation planes, vary in attitude but show an overall gentle to moderate pitch to the east northeast.

The foliation in the metamorphic rock is believed to be parallel to the original sedimentary bedding (Lovering and Goddard, 1950, p. 20), and the lineations are believed to be parallel to fold axes. The metamorphic rocks then represent the southern limb of a syncline that plunges to the east northeast.

Granite-metamorphic rock contact

Only about half a mile of the contact between the Pikes Peak granite and the Idaho Springs metamorphic rocks is in the Devils Head quadrangle, in sec. 9, T. 8 S., R. 69 W. In that section the contact is offset left-laterally by faulting and extends eastward through the southern part of the Kassler quadrangle. That part of the Kassler quadrangle was therefore included in this study.

In no place was the actual contact surface observed. Instead, the contact was mapped by determining the northernmost outcrops of granite and the southernmost outcrops of metamorphic rocks and by locating the contact between them. In most places this procedure resulted in an uncertainty of 50 to 100 yards. In a few places the contact could be located within 10 yards.

The attitude and nature of the contact must be inferred. In sec. 2, T. 8 S., R. 69 W., and eastward, the foliation in the metamorphic rocks strikes generally parallel to the trend of the contact and dips northward at an average value of about 60 degrees. The contact in this area is probably concordant with a similar northerly dip. Along the western part of the contact, however, the foliation of the metamorphic rocks appears in places to dip toward the contact and to stike at large angles to the trend of the contact. Either the contact is locally disconformable there or the foliation of the metamorphic rocks swings sharply to a conformable attitude in the covered interval near the contact.

Concordant and discordant lenses of granite, ranging in size from a few millimeters to several feet in thickness, occur within the wall rocks near the contact. In places the granitic material comprises fully half the mass of the rock, forming injection gneisses and migmatites. The proportion of granitic material decreases northward from the contact; but according to Scott (oral communication), granitic lenses and dikes may be found several thousand feet north of the contact. He also found the northerly extent of granitic lenses decreased from west to east along the contact. This observation may imply that the northerly dip of the contact increases from west to east.

Shearing in the granite at the contact in E½, sec. 1, T. 8 S., R. 69 W., and shallow gullies along the contact in places indicate possible local faulting along the contact; except in sec. 9., T. 8 S., R. 69 W., where a major fault has offset the contact, faulting at the contact appears to be unimportant.

There is almost a complete absence of xenoliths in the granite, both along the contact and within the body of the batholith. No discernable change of grain size or other textures was noted in the granite near the contact, although a chill border might be present in the concealed zone right at the contact. Dr. Gotthard Kraus (oral communication) found a decrease in the size of quartz and accessory mineral grains, though not in the feldspars, within a few hundred feet of the western edge of the Pikes Peak granite near Lake George, Colorado.

Absence of xenoliths is evidence against emplacement of the batholith by piecemeal stoping. Buddington (1959, p. 736) suggests block foundering, crowding aside of the walls, and uplift of the roof as other possible modes of batholithic emplacement in the mesozone. Block foundering cannot be ruled out, although there is no indication of large masses of contaminated granite or of large xenoliths. Noble (1952) called attention to the difficulty in demonstrating forcible intrusion into schistose rocks, such as the Idaho Springs formation in this area. Forcible intrusion, by crowding aside of the walls and/or uplift of the roof may be indicated by the generally conformable contact and the abundant injected material in the wall rocks. The metamorphic wall rocks show little or no more crumpling than in other areas remote from intrusives in the Front Range, hence it is felt uplift of the roof rocks was the dominant mode of intrusion.

North-trending faults

Three large north-trending faults, with their branches, cut the Devils Head quadrangle. These faults are here tentatively named the Devils Head-Deep Creek fault, the Pine Creek-Bear Creek fault, and the Jackson Creek-South Garber Creek fault.

The Devils Head-Deep Creek fault trends about N 10°W past the west side of Devils Head and down the valley of Deep Creek to the $N\frac{1}{2}$ sec. 9, T. 9 S., R. 69 W., where it turns sharply to N 45° W and continues northwestward into the Deckers quadrangle. The fault was mapped on the basis of its topographic expression and the presence of granitic fault breccia along its course; the actual fault surface was not seen. The fault is believed to be vertical or steeply dipping because of its relatively straight trace and because other faults in the area dip steeply. Direction and amount of movement can not be determined because no lithologic markers are cut by the fault.

The Pine Creek-Bear Creek fault trends almost due north down Pine Creek in sec. 4, T. 9 S., R. 69 W., and secs. 33 and 28, T. 8 S., R. 69 W., curves somewhat westerly to near Sprucewood in sec. 16, T. 8 S., R. 69 W., extends from there slightly east of north along Colorado Highway 67 to the northern edge of the Devils Head quadrangle, and thence follows the valley of Bear Creek north into the Kassler quadrangle. A branch extends southwesterly along Colorado Highway 67 from sec. 21, T. 8 S., R. 69 W. into the Deckers quadrangle. A short east-trending cross fault meets the main fault at the center of sec. 16, T. 8 S., R. 69 W.

Along much of its length, the fault is a poorly exposed crush zone a few feet wide, but in places the disturbed zone widens to a few hundred feet. In several places sandstone dikes and diabase dikes are in or associated with the fault zone. The dip of the fault could not be determined directly, but the dikes within the fault zone dip 80 to 85 degrees west, and a corresponding dip is inferred for the fault. The relatively straight fault trace supports this inference.

The overall movement of the fault cannot be determined, but in sec. 9, T. 8 S., R. 69 W., the granite-metamorphic rock contact has been left-laterally offset about 2700 feet. This offset could result from left-lateral strike-slip, from dip-slip with the west wall moved relatively down, or from a combination of movements. Strike-slip probably predominated. Along the cross fault in sec. 16, T. 8 S., R. 69 W., a diabase dike has been left-laterally offset about 400 feet.

The Jackson Creek-South Garber Creek fault extends north-northeasterly along Jackson Creek from the east side of Devils Head to the north edge of sec. 1, T. 9 S., R. 69 W., thence over a saddle and down the valley of South Garber Creek. A branch extends southeasterly from NW¼ sec. 23, T. 9 S., R. 69 W., into the Dakan Mountain quadrangle; another branch extends due south for two miles from SW¼ sec. 1, T. 9 S., R. 69 W.; and a third branch extends south-southeast two miles from NE¼ sec. 19, T. 8 S., R. 68 W.

The fault zone ranges in thickness from a few feet to a few tens of feet, and in a few places, to a hundred yards or so. The dip of the fault is believed to be vertical to steeply west on the basis of diabase and quartzite dikes within the fault zone. The straight traces of the fault and its branches indicate steep dips. The direction and amount of movement along the fault is not known because no markers are cut by the fault

The faults are believed to have been active at several different times. Precambrian faulting, widespread in the Front Range, may have involved these faults. Displacement at or shortly after the end of the Cambrian period is evidenced by the sandstone dikes that lie in the fault zones. Diabase dikes, of probable Tertiary age, that occur in and associated with the fault zones were probably intruded during renewed movement on the faults. Still later movement is shown by shears and slickensides within the diabase dikes. Recently, however, the area has been seismically stable, as indicated by the numerous balanced rocks and perched boulders found throughout the area.

Monoclinal folds

At the western edge of the Denver Basin, where it adjoins the Front Range, the sedimentary rocks have been sharply bent up in monoclinal folds (Warner, 1956, p. 143; Osterwald and Dean, 1958). These folds are well developed along the eastern edge of the Devils Head area, particularly in the northeast and southeast corners, where the edges of the resistant upwarped strata form prominent hogbacks.

At the mountain front, beds generally dip steeply eastward, although in places they are vertical or overturned. Within half a mile east of the mountain front, the beds are nearly or quite horizontal, so that flexure of 90 degrees or more occurs in this distance.

The folding is due to uplift of the Front Range which dragged the sedimentary rocks up with it. The folding involves the Dawson arkose, so the uplift can be no earlier than early Tertiary. Unconformities within the Dawson and lower dips in the upper part of the Dawson suggest that the uplift was going on during Dawson time.

Thrust faults

Along with the monoclinal folding, thrust faults or high-angle reverse faults mark the boundary between the Front Range and the Denver Basin. Early workers, such as Lee (1902), failed to recognize these faults, and explained the disappearance of certain strata along the mountain front by arching during sedimentation. Ziegler (1917) first called attention to the faults and showed that their reverse movement and steep dips could be explained by lateral compression combined with pronounced vertical uplift.

In the Devils Head quadrangle the thrusts trend north to somewhat west of north, generally parallel to the strike of the sedimentary rocks. Two or three parallel fault traces occur at the surface; these are believed to merge at depth. The dip of the faults cannot be observed directly, but some data on dips are available from wells north and south of the area (Bauer, 1958, p. 85-86). In southern Perry Park, where the Fountain formation is thrust over Pierre shale, the fault dips 50 degrees west. In sec. 32, T. 7 S., R. 68 W., a well designed to intercept the fault went to a depth of 1261 feet without encountering the fault; the fault plane is believed to dip 85 degrees or more.

Total movement on the faults cannot be determined; it probably varies from place to place. Along the Jackson Creek road in sec. 17, T. 8 S., R. 68 W., granite has been thrust over the Benton formation, a stratigraphic throw of more than 4300 feet. Additional thrusting within the Dawson is indicated. At Bee Rock, in sec. 8, T. 8 S., R. 68 W., granite has been thrust over the Benton formation, and the Benton in turn has been thrust over the Dawson; the stratigraphic throw there is about 11,000 feet. Actual movement on the faults was considerably greater than this; Warner (1956, p. 139) suggested movement of a few miles.

The faulting occurred during early Tertiary (Laramide) time. Although east-west compression is indicated by crustal shortening across the Front Range (Warner, 1956, p. 139), the steep dips of the faults and the strong monoclinal folds associated with them indicate that vertical uplift played an important if not dominant role in the deformation.

Cross faults

A series of east- to northeast-trending cross faults cut the belt of thrusting and folding along the east edge of the Front Range. Fifteen such faults were mapped in the Devils Head quadrangle and other faults may exist under cover.

The faults are poorly exposed along gullies, and their attitudes cannot be determined. They are believed to be vertical or very steeply dipping. Movement on the faults is largely dip slip, amounting to several tens to a few hundred feet in the central parts and decreasing toward the ends. The faults die out in the granite to the west and in the sedimentary rocks to the east.

The faults are of Laramide age, but later than the thrust faults which they offset. They probably represent readjustment, within the folded and faulted belt, to the earlier deformation. Their trend, roughly normal to the disturbed belt, indicates they may have developed along tensional fractures formed during the east-west compression that formed the thrusts and folds.

Joints

Throughout the granite in the Devils Head quadrangle, a consistent joint system is developed. Similar joints may be

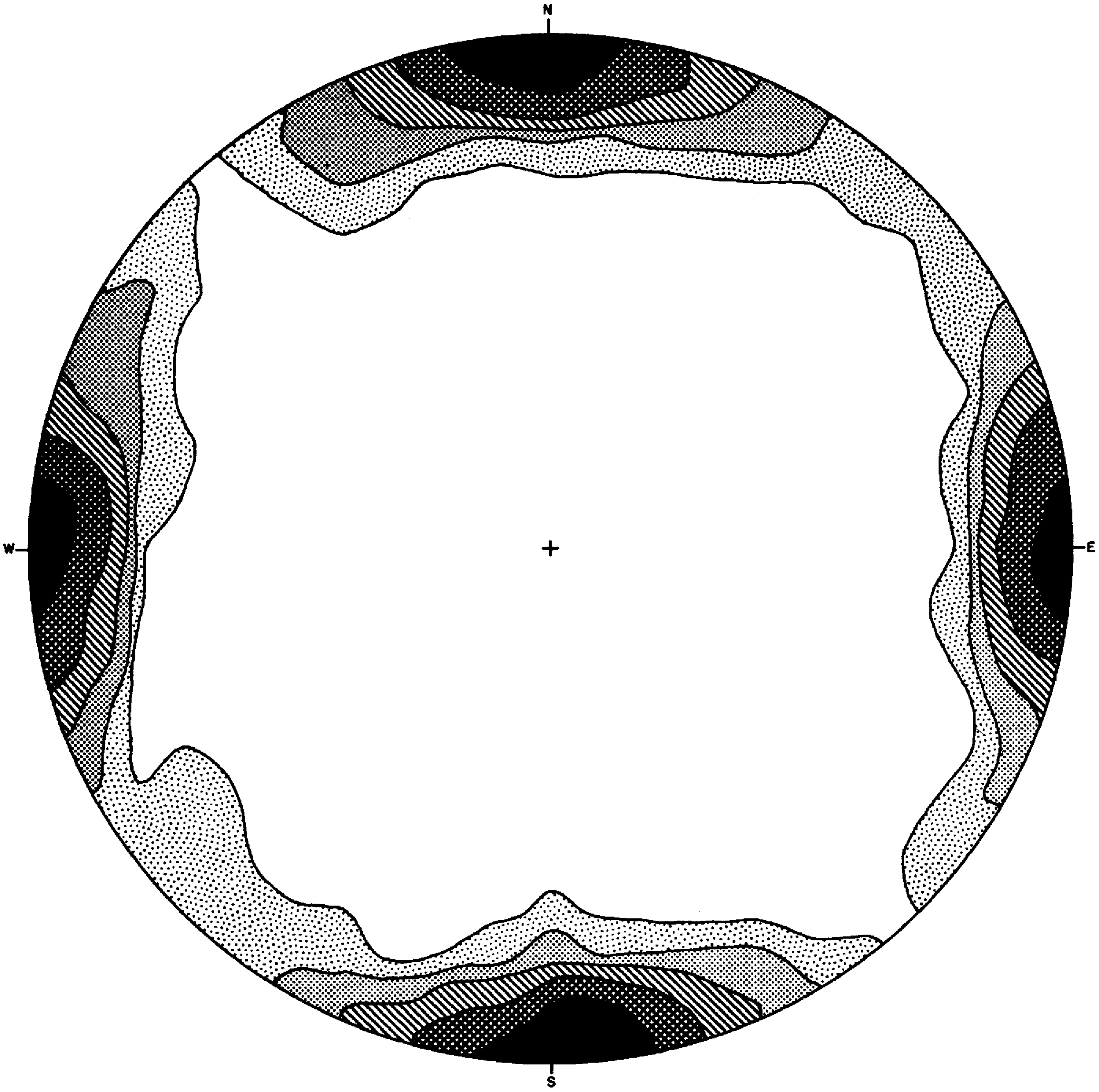

PLATE 5. FREQUENCY-DISTRIBUTION DIAGRAM OF THE POLES OF 1450 JOINTS IN PIKES PEAK GRANITE, DEVILS HEAD QUADRANGLE, DOUGLAS COUNTY, COLORADO. (One-percent counter. Contours at 0.5, 1, 2, 4, and 8 percent.)

recognized in the metamorphic rocks, but are combined with foliation joints and others so that the pattern is less regular. Joints in the sedimentary rocks were not mapped, as they are generally poorly developed and unsystematic.

The joints in the granite fall largely into two mutually perpendicular sets that, on the average, strike north-south and east-west and dip vertically. Steeply dipping joints not included in one of these sets are much less abundant and flat-lying joints are uncommon.

Individual joints within the sets may vary several degrees along dip and strike and may depart, individually or in localized areas, from the average attitude; but the overall pattern is remarkably consistent, as shown in Plate 5 which is a frequency-distribution diagram of the poles of 1450 joints.

The conclusion that the joints are related to the faulting seems inescapable. The north-south joints are parallel and sub-parallel to the trend of the faults, and near the faults the north-south joints are weaker and less closely spaced, as though areal stresses had been relieved by faulting in these zones with less tendency to cause jointing. In the east-west direction, where faulting is not developed, the joints show no such variation in development.

Although the joints are of Laramide age, their formation was strongly influenced by an earlier, probably Precambrian, structural framework. The faults to which they are related were developed probably during Precambrian time, certainly as early as shortly after the Cambrian. Compressive forces during Laramide time caused renewed movement along the north-trending faults and the formation of the north-south joints; the east-west joints developed as a complementary set.

GEOLOGIC HISTORY

The formation of the metamorphic and igneous rocks of the Devils Head area occurred well over a billion years ago, as demonstrated by a number of workers using a variety of dating methods (see following section on Age Determinations). Still earlier events, not dated and perhaps impossible to date, can be recognized.

The earliest demonstrable episode is the uplift and subsequent erosion of a large mountain mass. Whether the mountains had been involved in still earlier cycles of uplift, erosion and deposition, or whether they represented part of the primeval crust of the earth can only be conjectured. In any case, sediments derived from them were deposited to form sandstones, arkoses, shales, and some limestones that later became the Idaho Springs formation. Deposition was largely marine, as indicated by the abundance and areal extent of shale-derived rocks; but some meta-conglomerates are probably of continental origin. Diorite sills were intruded into this series of sedimentary rocks and andesite lava flows poured out on the surface.

Following deposition of the Idaho Springs rocks, the region underwent a period of strong deformation and regional metamorphism; syntectonic intrusion probably accompanied the deformation. Under these conditions the Idaho Springs rocks were converted to gneisses, schists, and migmatites, and were strongly crumpled and faulted.

The region was then intruded by a number of granitic masses (cf. the Indian Creek plutons of Boos and Aberdeen, 1940) none of which occurs in the Devils Head quadrangle. Emplacement of these plutons was followed by intrusion of a great granitic mass to form the Pikes Peak batholith.

After emplacement, solidification, and cooling of the Pikes Peak granite, the area was subjected to a long period of erosion, during which the metamorphic rock cover was removed from the granite over part of the area. By Upper Cambrian time, a very flat peneplain had developed on the granite and the metamorphic rocks in the Devils Head area.

During Upper Cambrian time, a sea advanced from the east, covering the Devils Head area and depositing the Sawatch sands. Before the Sawatch sands had been indurated, probably in late Upper Cambrian time, but possibly somewhat later, a series of north-trending faults developed into which quicksands of the Sawatch were injected downward by the pressure of overlying sediments. These fault fillings formed the sandstone dikes of the Devils Head and adjacent areas.

Deposition of marine sediments probably continued during the Ordovician period. No Ordovician rocks are found in the Devils Head quadrangle, but the Manitou limestone crops out in Perry Park just south of the quadrangle and it appears that this formation once covered at least part of the Devils Head quadrangle.

During the Silurian and Devonian periods, the area was probably gently uplifted and lightly eroded. No Silurian rocks are known anywhere in this region, and Devonian rocks have been found only in the subsurface to the east. An unconformity is found at the base of Mississippian rocks a few miles south of the Devils Head.

Though not directly evident, a Mississippian sea may have covered at least part of the quadrangle. Mississippian limestones are found a few miles to the south, but if they were also deposited in the Devils Head area, they were eroded away before deposition of Pennsylvanian sediments began.

The "Ancestral Rocky Mountains" were uplifted in Pennsylvanian time, and clastic sediments derived from their erosion were deposited in a piedmont environment to form the Fountain formation. Marine fossils found in the Fountain formation a few miles east of the Devils Head area indicate a nearby sea, and it is possible that intermittent marine conditions existed within parts of the Devils Head quadrangle.

Erosion of the mountains and deposition of clastic sediments continued in Permian time. The Lyons sandstone was laid down as a strandline deposit. As the mountains were reduced in height, shales and limestones of the Lykins formation were deposited in a shallow-water, near-shore environment, possibly under deltaic conditions. These conditions persisted into Triassic time.

During the Jurassic period, the land was relatively quiescent. Shales, marls, and gypsum deposited under lagoonal or estuarine conditions gave rise to the Ralston Creek formation. The Morrison formation was deposited as sands, muds, and marls on flat lowlands, covered by lakes and swamps, over which dinosaurs roamed.

Epeirogenic uplift in late Jurassic or early Cretaceous time is reflected in the conglomerate that in many places forms the base of the Dakota formation, which was deposited largely under near-shore continental conditions, with some marine phases.

Near the end of Dakota time, the land began to subside and a great sea moved into the area from the east. As subsidence continued, shales and limestones were deposited to form the Benton Niobrara and Pierre formations. Sedimentation and subsidence apparently proceeded at similar rates, for there is no evidence of very deep or very shallow water deposition.

Subsidence ceased and renewed uplift began during Pierre time, so that by Fox Hills time the sea had partially retreated and the Fox Hills sandstone was deposited in shallow waters near shore, probably as a series of off-shore bars.

Continued uplift resulted in the final withdrawal of the sea at the close of Fox Hills time and the sands and clays of the Laramie formation were deposited on low, broad, piedmont plains. The climate was warm and humid, and the plains were covered with abundant vegetation, which accumulated in the numerous swamps to form lenses of coal.

Gentle uplift and erosion followed Laramie time, and initiated the Laramide revolution in this area. Pebbles and coarse arkosic sands derived from the newly uplifted mountains were laid down as the Dawson arkose, which unconformably overlies the older formations. Uplift, erosion, and deposition alternated during Dawson time, as indicated by the local unconformities within the Dawson.

Laramide volcanic activity was widespread during Dawson time. Andesitic volcanic debris abounds in the Denver formation, which is equivalent to the Dawson. Although no volcanic material was found within the Dawson, a number of diabasic andesite dikes cut the Pikes Peak granite in the Devils Head quadrangle. These dikes are presumed to be equivalent in age to the andesitic material in the Denver formation, that is, early Tertiary, although they could be much earlier, as they have not been observed cutting any rocks younger than the post-Sawatch sandstone dikes. These andesitic dikes may represent the feeders of the volcanoes that contributed to the Denver formation, as the source of that material has not been found. The dikes, almost invariably found in faults within the Pikes Peak granite, probably reflect renewed fault movement accompanied by volcanism.

Rhyolite flows occurred at the close of Dawson time, and probably covered part of the Devils Head quadrangle, although any such flows in this area have been completely removed by erosion. Douglas rhyolite caps several buttes just east of the Devils Head quadrangle. Similarly, the Castle Rock conglomerate may have been deposited and later eroded from this area.

At the climax of the Laramide revolution, strong monoclinal folding and thrust faulting involved the rocks along the margin of the Front Range throughout most of its length. This faulting was probably accompanied by renewed faulting along the pre-existing faults in the Precambrian rocks, as the andesite dikes have been affected by post-dike faulting. A series of cross-faults, probably not much later than the thrusting, offset the thrust planes and sedimentary rocks, as well as the granite, in the Devils Head quadrangle.

The area was extensively peneplained in mid-Tertiary time, and since then there have been two, or perhaps more, stages of uplift and erosion which account for the present topography.

Wisconsin glaciation, which affected much of the Front Range, has left no record in this area. Present-day streams, actively cutting into the rocks along their steeper reaches, are depositing alluvium upon debouching onto the plains.

AGE DETERMINATIONS

In recent years a variety of methods, based on radioactivity, have been developed for dating geologic events. These methods are particularly effective in the study of igneous and metamorphic rocks, where paleontological and stratigraphic correlation and dating are generally impossible. In such rocks structural relationships may often be used to infer relative dates, but to correlate separated areas and to determine actual time intervals and dates, the newer methods must be employed.

Several age studies of rocks and minerals from the Front Range have been made; those that are applicable to Devils Head quadrangle rocks are summarized here.

Only one age determination has been reported from the Devils Head quadrangle itself. Hillebrand (1888) analyzed three samarskites from Devils Head Mountain, and from these analyses Holmes (1931, p. 338) calculated the lead ratios 0.142, 0.152, and 0.160. According to Lovering and Goddard

(1950, p. 28), the age indicated is approximately 1000 million years. The formula

$$\text{Age (m.y.)} = 7600 \frac{Pb}{U + 0.36Th}$$

yields 1080; 1160; and 1220 million years respectively for these ratios. The youngest of these dates, derived from the freshest material, is probably the most reliable. It agrees well with dates reported by Hutchinson (1959b) for the Pikes Peak granite.

Age determinations of the Pikes Peak granite from other areas have been made using the potassium-argon method on mica (Aldrich and others, 1958; Giffin and Kulp, 1960; Hutchinson, 1959a, b; Phair and Gottfried, 1958; Tilton and others, 1957); the strontium-rubidium method on mica and lead-uranium-thorium isotope method on zircon (Aldrich and others, 1958; Phair and Gottfied, 1958; Tilton and others, 1957); and the lead-alpha method on zircon (Phair and Gottfried, 1958). The results range widely for the different methods, but there is generally good agreement between different investigators using the potassium-argon method on biotite; their results indicate a probable age of 1050 million years for the Pikes Peak granite.

Hutchinson (1958a) reported a potassium-argon age of 1240 million years for the Double Head pluton, one of the Indian Creek group. He stated (1960, p. 171) that, on the basis of structural relations, the Double Head pluton appears to be earlier than the Pikes Peak granite.

Most of the mineralization of the Front Range is believed to be of Laramide age (Lovering and Goddard, 1950). Pitchblende from the Central City district has been dated by lead-uranium isotope ratios (Eckelmann and Kulp, 1957, p. 1127-1128) as about 60 million years old. The sphalerite-galena-fluorite-barite veins of the Devils Head quadrangle are probably closely similar in age.

On the basis of age determinations, the igneous-metamorphic history of the Devils Head area can be summarized as follows: intense orogeny and metamorphism, giving rise to Idaho Springs formation, about 1500 million years ago; intrusion of Indian Creek plutons and related bodies 1240 million years ago; intrusion of Pikes Peak granite 1050 years ago; and hydrothermal mineral deposition 60 million years ago.

ECONOMIC GEOLOGY

As of the end of 1960, the only mineral production from the Devils Head quadrangle is disintegrated granite for road metal. Although it is felt that the economic mineral potential of the area is low, the exploration and mining that have been carried on in the past and the possible exploitation of some materials in the future warrant discussion.

Gold

A small amount of placer gold has been produced from Newlin Gulch about 10 miles northeast of the Devils Head quadrangle. (Henderson, 1912, p. 387, 410) reports an output of 4.02 fine ounces in 1910. More recently, three ounces were produced in 1948 and three more in 1956 (Martin, 1948, p. 1457; Kelly, Kerns, and Parker, 1956, p. 264). According to Emmons (Emmons, Cross, and Eldridge, 1896, p.270-273) and Butler (1912), the gold was found in alluvium in the bottom of the gulch as well as in Monument Creek sedimentary rocks well above the stream. He concluded that the gold in the stream bottom was derived from the Monument Creek beds and that the most probable source of the gold in the Monument Creek rocks was in the area of the Pikes Peak granite. Within the granite, many prospect pits indicate the search for gold in this area, but so far as can be ascertained, none of these yielded any ore.

Although the former production indicates a possibility of buried placer gold in the Dawson arkose, or an undiscovered lode in the granitic area, prospecting seems unwarranted, especially in view of the probable small size and low grade of such deposits and of the current depressed state of the gold-mining industry.

Coal

Although no coal is now mined in this vicinity, Eldridge (Emmons, Cross, and Eldridge, 1896, p. 327-329) described the Douglas coal mine which was operating in 1890 in the Sedalia coal field, apparently a short distance north of the Devils Head quadrangle; he mentions half to three-quarters of a mile of workable coal. No coal was seen during this study, and as the area of Laramie outcrops in the Devils Head quadrangle is rather small, there is little likelihood of finding workable coal. It is not feasible to prospect for coal beneath the Dawson arkose.

Petroleum

No oil wells have been drilled in the Devils Head quadrangle, although Shell Oil Co. has drilled three core-drill holes for structural information. The complex structure makes the discovery of suitable traps difficult. Although the possibility of oil in this area exists, data are insufficient to justify a wildcat well.

The nearest production was about 18 miles north of this area in the SW¼NE¼NW¼ sec. 7, T. 5 S., R. 69 W. That well, the S. D. Johnson Pallaro No. 1, produced initially 100 bpd, but was shut down after a few months. No offset wells were drilled.

Clay

Although clay has been mined extensively in this region from the Dakota and Laramie formations, and Bauer (1959, p. 102) mentioned a clay pit operating only a mile and a half north of this area, no clay deposits are known in the Devils Head quadrangle. The limited outcrop area of clay-bearing formations and the poor quality of material observed in them make it unlikely that clay can be mined in this area.

Gypsum

The occurrence of gypsum in the Perry Park area has been known for many years, and some gypsum was mined formerly (Lakes, 1904, p. 87; 1905a, p. 312), but no production has been made in recent years, and the gypsum has attracted little notice except from mineral collectors (Griswold, 1940; Pearl, 1948, 1951, p. 98). The gypsum, interbedded with shale, occurs in the Ralston Creek formation. Beds are from an inch to about four feet thick. Although much of the gypsum is too impure for making plasters and cements, it is suitable for soil conditioning and similar uses where some impurity can be tolerated. A moderate tonnage of this impure gypsum is available in the Devils Head quadrangle.

Silica Sand

Vanderwilt (1947, p. 262-264) mentions the occurrence of beds of sandstone, in the Dakota and the Lykins formations, suitable for use as molding sand or for making glass. Some of this sandstone has been quarried just north of the Devils Head quadrangle. Possibly, similar suitable sandstone beds could be found in the Dakota formation within the quadrangle, though there is insufficient demand for this material to warrant development at the present time.

Gem Stones

Gem stones, including topaz, amazonite, and smoky quartz, have been produced for many years from various pegmatites in the Devils Head quadrangle, especially from the claim now held by the Colorado Mineral Society just southwest of Devils Head. Perhaps the largest well-formed and well-preserved topaz crystal ever found in North America came from this deposit. (Pearl, 1951, p. 95). Although the mine was worked out in 1934, (Arthur Montgomery, oral communication), topaz fragments are still to be found in the dump material. Gems and specimens worth a few hundred dollars are taken from this and other nearby pegmatites every year (Kelly and others, 1955, p. 270; 1956, p. 281). Diligent search would doubtless lead to the discovery of other gem-stone deposits in this area, although the size and value of such probable discoveries is more suited to the mineral collector than to the miner.

Limestone

Small amounts of limestone from the Glennon and the Timpas limestones have been quarried in this vicinity. The limestone has been used as a metallurgical flux and has been burned for lime and plaster. No limestone was being produced in the area during 1960. Because the area of limestone outcrop in the Devils Head quadrangle is small, it is unlikely that more than small amounts can be produced.

Feldspar

Several thousand tons of feldspar has been produced from a number of pegmatites in the Devils Head quadrangle; no mines are now operating. The last recorded production was 210 tons from the Three Musketeers mine in 1956 (Kelly, Kerns, and Parker, 1956, p. 281). Several of these pegmatites still contain feldspar, mostly pink microcline with some white to pink albite; it is irregularly mixed with pods of quartz, and considerable hand cobbing would be required before any rock mined could be shipped and sold. Many small pegmatites were seen during this study, but no large, unexploited pegmatites were encountered, and it seems unlikely that new mines can be opened.

Early in 1959, International Minerals and Chemical Corp., the only custom grinder of feldspar in Colorado, closed its plant at Denver. It is probable, therefore, that unless greatly increased demand for feldspar occurs in the future, no more production will be made from this area.

Radioactive and Rare Earth Minerals

Eakins (1886) described allanite and gadolinite from Devils Head, and Hillebrand (1888) reported on samarskite and cyrtolite from the same locality. Allanite, a ubiquitous accessory mineral in the granite, occurs as tiny veinlets in places. Veins of allanite up to six inches wide have been found near Conifer, Colorado, although none were seen in the Devils Head quadrangle. A small pegmatite prospect just north of the Devils Head camp ground contains tiny scattered crystals of black radioactive minerals; samarskite and fergusonite have been identified (J. D. Whitman, oral communication). In the California pegmatite, trace amounts of a radioactive mineral, probably samarskite, were found. In none of these occurrences in the Devils Head quadrangle is there any significant quantity of rare earths or radioactive elements, and no production could be made even as a by-product. Chances of finding other, larger deposits, are considered remote.

Stone

Besides the limestone discussed above, other varieties of stone in the Devils Head quadrangle have potential or actual value.

The Pikes Peak granite has been quarried locally on a very small scale. The granite is too coarsely granular to be desirable as a monumental stone, and its rapid weathering probably precludes extensive use as a building stone although it has been so used in the past (Lakes, 1905b). Much of the granite at the surface is highly decomposed and friable, but large quantities of sound rock are available should demand arise.

Sandstones from the Laramie, Fox Hills, Dakota, Lyons, and Fountain formations have been quarried in the Foothills region (Lakes, 1901), though with the exception of a few quarries in the Dakota, no quarries have operated in the Devils Head vicinity. The current lack of demand for dimension stone and other varieties militates against quarrying operations, although there are deposits of all these stones in the area. The Lyons sandstone in this area appears to lack the flagginess that has sustained a demand for it in other places.

Crushed stone for road metal and similar construction uses has been produced from two quarries at the northern end of the

Devils Head quadrangle. Only one of these is still operating. The granite at these quarries has been weathered and disintegrated nearly or completely to <u>grus</u> (Stokes and Varnes, 1955, p. 68), and can be dug and loaded by bulldozer or power shovel without blasting. The deposits, ranging up to 50 feet in depth, extend for a few hundred feet horizontally. Other areas of deeply weathered granite or <u>grus</u> are known; reserves of this material are large.

The Dawson arkose has been quarried on a small scale along the Jackson Creek road and elsewhere, although no production was made during the period of this study. In places this formation is soft and friable so that it may be dug by power shovel or bulldozer without blasting. This material, in large reserves, could be used with little treatment as aggregate in various forms.

Lead and Zinc

In secs. 8 and 17, T. ~~8~~ 9 S., R. 68 W., the Pikes Peak granite is cut by a number of mineralized veins that trend about N 10°W and dip 65°W. The veins range in width from 6 inches to 2 feet, with much pinching and swelling; the average width is less than a foot.

The veins contain brecciated granite and quartz with a filling of white quartz; white barite, purple, pale-green and colorless-to-white fluorite, and scattered flecks of galena and rosin-colored sphalerite. Galena is altering to anglesite and cerussite. One vein contains abundant gray chert and numerous breccia fragments of dark-green altered diabase dike rock. Crustification, comb structure, and small vugs indicate probable open space filling under mesothermal to epithermal conditions.

Weathered granite debris covers the slope and makes it impossible to trace the veins continuously. Seven veins were recognized and others may be concealed beneath the slope wash. The length of the mineralized area is about half a mile, but individual veins could be traced only a few tens of feet.

The veins are believed to be of Tertiary age, because of the breccia fragment of diabase dike found in one of them and because much of the mineralization of the Front Range is of that age (Lovering and Goddard, 1950).

Considerable exploration was done on the deposit many years ago, but it is doubtful that any ore was produced. No reference to any base-metal production from anywhere in Douglas County could be found in the literature. Workings consist of two caved adits, two inclined shafts that are now caved and filled to within 40 and 20 feet of the collars, and a number of prospect pits. A little prospecting has been done here in recent years, but no evidence of current activity was seen in 1960, and no claim notices could be found.

Although lead and zinc ore might be encountered at depth or under cover at this locality, the narrow veins and sparseness of metallic minerals offer little encouragement to prospecting.

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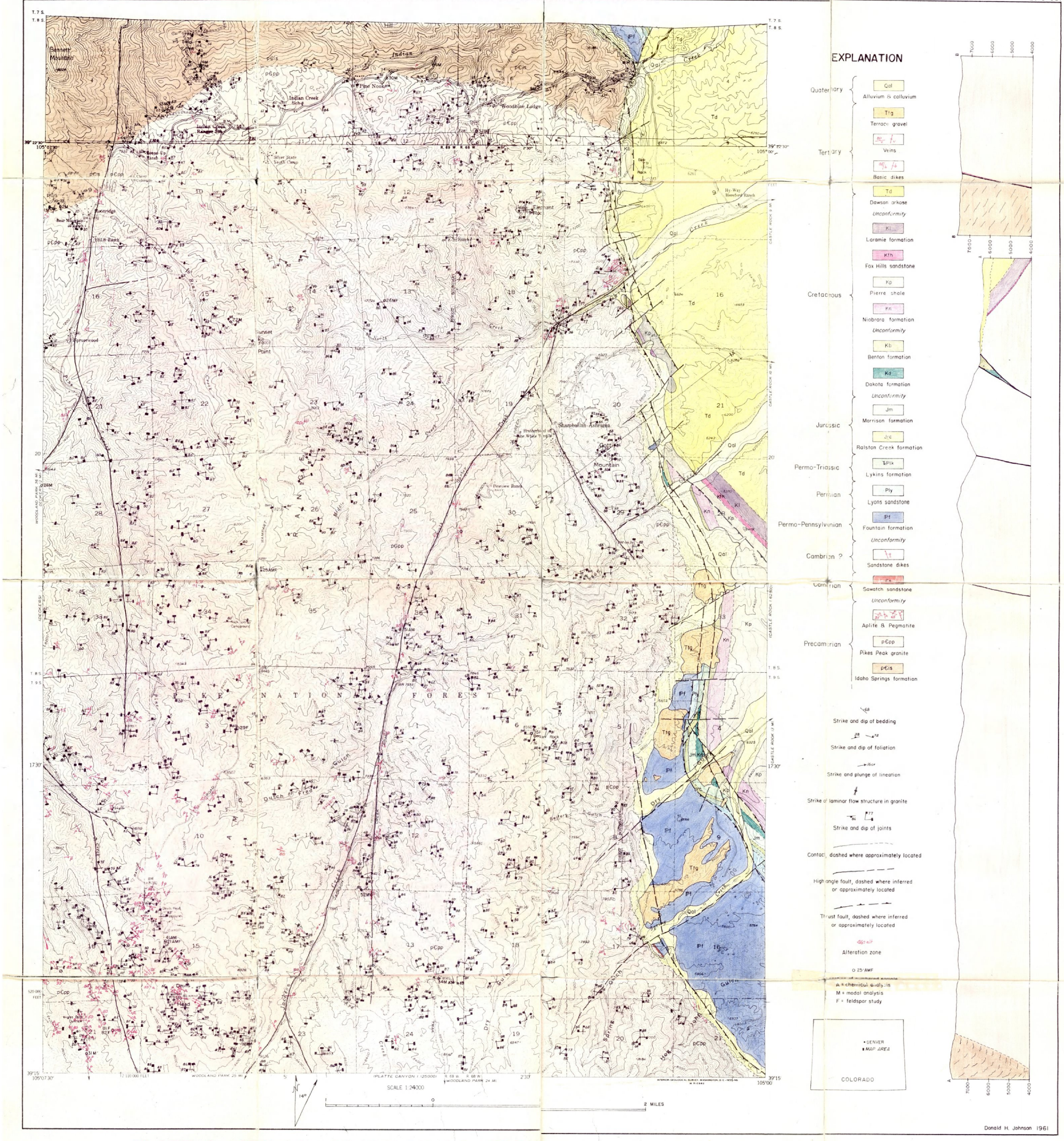
PLATE

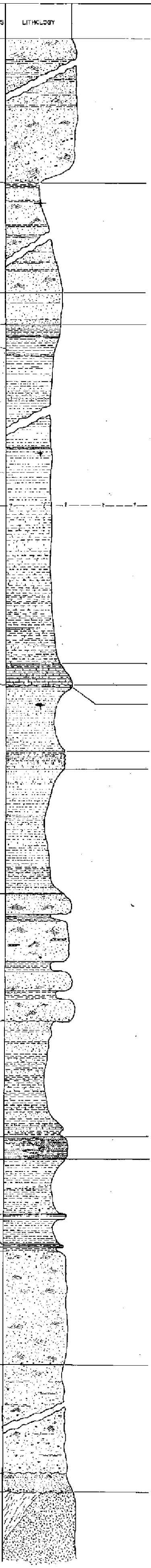
COLORADO SCHOOL OF MINES

THESIS 901



Donald H. Johnson 1961

PLATE 2. - GEOLOGY OF THE DEVILS HEAD QUADRANGLE, DOUGLAS COUNTY, COLORADO.



ERA	PERIOD	FORMATION	MEMBER	THICKNESS	DESCRIPTION
CENOZOIC	TERTIARY	Dawson		2000+	Sandstone; buff, arkosic, coarse-grained, angular quartz and feldspar sand in a clay and mica matrix, contains pebbles up to two inches in diameter, cross-bedded and massive, large percentage of detrital chert in lower portion.
MESOZOIC	CRETACEOUS	Laramie		600	Sandstone; gray to yellow, fine-grained, sub-angular, quartz sand, cross-bedded and massive, interbedded with black and gray clay shale.
		Fox Hills		80	Sandstone; brown, very fine-grained, sub-rounded quartz sand, limonitic, fossiliferous, thin-bedded to massive, some thin interbedded black shale.
		Pierre		5500	Shale; black, thin-bedded, fossiliferous, occasional thin nodular, argillaceous, limestones. Contains a zone of sandy shale approximately 1000 feet from the top (Hygiene sandstone?). Upper portion contains numerous thin limonitic sandstones transitional to the Fox Hills formation.
		Niobrara	Apishapa	500	Shale; light gray to black, calcareous, some thin white argillaceous limestones in lower portion.
			Timpas		Limestone; white, dense, chalky, argillaceous, fossiliferous, thin-bedded. Upper portion interbedded with gray calcareous shale.
		Benton	Codell	580	Limestone; tan, medium-bedded, crystalline, fossiliferous.
			Carlile		Shale; black, thin-bedded, calcareous in part.
			Greenhorn		Limestone; light tan, highly argillaceous, fossiliferous, thin-bedded, interbedded with light gray calcareous shale.
			Graneros		Shale; black to light gray calcareous in part, thin-bedded contains some thin limonitic siltstones and occasional thin bentonite beds.
		Dakota		350	Sandstone; gray, very fine-grained, sub-rounded quartz sand in a silt matrix, limonitic, cross-bedded, thin-bedded to massive. Upper portion is transitional to the Benton formation. Shale; light gray thin-bedded, platy, abundant plant fragments. Sandstone; light gray, fine-grained, sub-rounded quartz sand, contains lenses of intraformational conglomerate massive and cross-bedded. The upper portion consists of thin-bedded gray siltstone. Shale; dark gray. Sandstone; white to tan, fine-grained, sub-rounded, quartz sand, some clay, limonitic, thick-bedded to massive, cross-bedded and conglomeratic (granules) at base. Shale; dark gray to black. Sandstone; tan to pink, fine-grained, sub-rounded quartz sandstone, lower portion conglomeratic, containing quartz and chert granules, massive and cross-bedded.
	JURASSIC	Morrison		350	Marl, shale, sandstone, and limestones; variegated, red, purple, gray, green and tan. Thin (Chara?) limestone near base. Upper portion contains massive, soft quartz sandstones, alternating with clay shale.
		Ralston Creek		50	Siltstone; calcareous, and marl; gray, non-resistant north of Jarre Canyon. In northern Perry Park it consists of alternating gray gypsiferous shale and white massive to crystalline gypsum.
	TRIASSIC	Lykins	Strain	190-210	Shale; red, silty, thin-bedded.
			Glennon		Limestone; white, lower part fine-crystalline, massive, upper portion thin-bedded, platy.
PALEOZOIC	PERMIAN		Bergen		Shale; red, silty, thin-bedded.
			Falcon		Limestone; white, fine-crystalline, thin contorted laminations.
			Harriman		Shale; red, silty, thin-bedded.
		Lyons		250-310	Sandstone; pink to tan, fine-grained, sub-rounded quartz sand, cross-bedded to massive, conglomeratic (pebbles up to 1" in diameter) in basal and upper portions.
	PENNSYLVANIAN	Fountain		2500	Sandstone; and conglomerates red and white, arkosic, coarse-grained, angular, poorly sorted quartz and feldspar in a clay and mica matrix, (pebbles up to two inches in diameter), cross-bedded to massive. Occasional thin micaceous maroon siltstone lenses.
	CAMBRIAN	Sawatch		55	Sandstone; white-fine-grained, well-rounded, bedded quartz sand, lowermost portion quartzitic and conglomeratic, (granules), some cross-bedding in upper portion.
PRECAMBRIAN					Gneisses, schists, and hornfelses of the Idaho Springs formation, and granite, leucogranite, quartz monzonite, and aplites and pegmatites of the Pikes Peak batholith.

PLATE 3. STRATIGRAPHIC COLUMN OF THE DEVILS HEAD QUADRANGLE, DOUGLAS COUNTY, COLORADO.

COLORADO SCHOOL OF MINES

THESIS 901

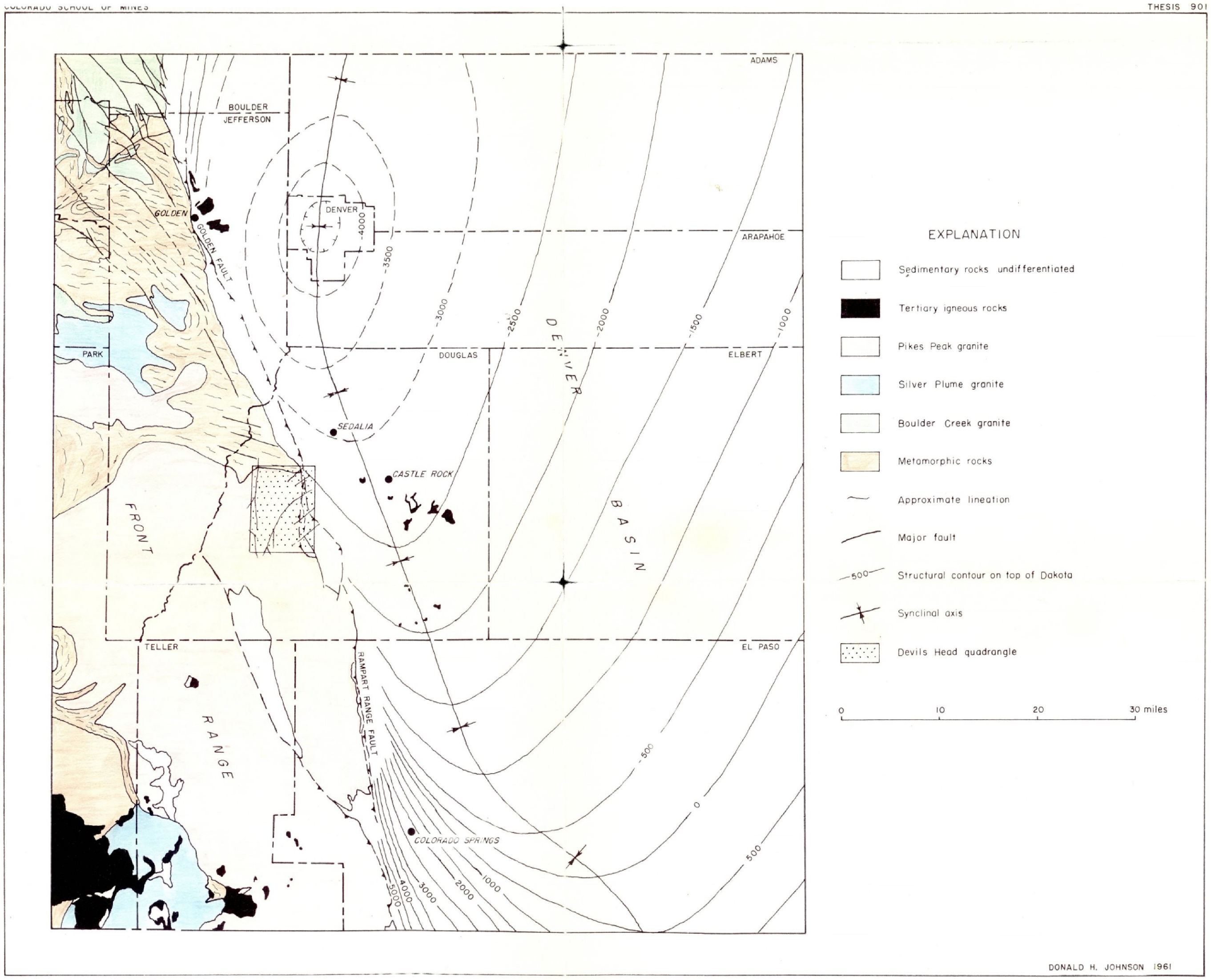


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PLATE 4. PRINCIPAL STRUCTURAL FEATURES OF CENTRAL COLORADO.