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GEOLOGY OF THE SAWATCH RANGE, COLORADO

by

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Plate I. Geologic map and sections of the Sawatch Range, Colorado, opposite page 472

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Introduction

The data for the accompanying map were obtained during the summers of 1931-1933 by geologic parties from Northwestern University, in a study of the pre-Cambrian and related rocks of the Sawatch Range.

The Sawatch Range of central Colorado trends almost due north from Monarch Pass, west of Salida, for a distance of nearly 80 miles to where it plunges beneath the synclinal valley of Eagle River. The area included on the accompanying map lies, roughly, between 38° 30′ and 39° 40′ north latitude and 106° 10′ and 106° 50′ west longitude.

The writers wish to acknowledge the valuable aid and co-operation given by the U. S. Geological Survey, in the use of field equipment and in the services and advice of its members, Messrs. B. S. Butler, C. H. Behre, Jr., T. S. Lovering, and Q. D. Singewald. Thanks are also due to Messrs. E. P. Chapman, Marvin Kleff, Douglas Platt, and Fred Smith, all of Leadville, for assistance given and courtesies shown during the course of the field work. The following graduate students of Northwestern University have given valuable aid in the field: Paul Averitt, R. S. Cannon, D. V. Harris, A. D. Hoagland, E. F. Osborn, and E. H. Rainwater. The support of the Northwestern University Research Fund, which made these studies possible, is gratefully acknowledged. To the Geology department of the University of Cincinnati, for the use of laboratory facilities during the preparation of the map, thanks are due.

Mention should also be made of the fact that some of the map data in the Redcliff, Leadville, Aspen, Twin Lakes, and Monarch-Tomichi districts have been generalized from maps accompanying published reports on these areas.[3] The

[3]Crawford, R. D., and Gibson, Russell: Geology and ore deposits of the Redcliff district, Colorado: Colo. Geol. Survey Bull. 30, 1925.
Emmons, S. F., Irving, J. D., and Loughlin, G F., Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geol. Survey Prof. Paper 148, 1927.
Spurr, J. E., Geology of the Aspen mining district, Colorado: U. S. Geol. Survey Mon. 31, 1898.
Howell, J. V., Twin Lakes district of Colorado: Colo. Geol. Survey Bull. 17, 1919.
Crawford, R. D., Geology and ore deposits of the Monarch and Tomichi districts, Colorado: Colo. Geol. Survey Bull, 4, 1913.

special designations of the pre-Cambrian formations in these areas are, however, those of the writers.

General Description

The Sawatch Range forms a part of the most westerly of two granite belts which cross Colorado with subordinate axes en echelon. This western belt "trends south from Wyoming as the Park Range, but turns southeastward as the Gore Range, and again south, past Leadville, as the Mosquito Range. Meantime, the main axis is offset to the west and is found in the Sawatch Range whose southward continuation is buried beneath the San Juan eruptives."[4]

The topography of this area is extremely rugged, with a maximum relief of more than 7,000 feet, from the tops of the highest peaks (many of which, such as Mts. Massive, Elbert, Harvard, Princeton, and Yale, exceed 14,000 feet in elevation) to the floor of the Arkansas Valley near the southern end of the range, less than 7,000 feet above sea level. The slopes of the range are trenched by steep-walled valleys 2,000 feet or more in depth, most of which head in cirques and show other marks of erosion and deposition by glaciers.

The summits of the range offer interesting contrasts in glaciated and unglaciated crests. For example, La Plata Peak, 7 miles southwest of Twin Lakes, is thoroughly glaciated with cirques nearly meeting on three sides, whereas Mt. Elbert, 6 miles north and slightly higher, presents a smooth rounded summit untouched by ice action. Many valleys on both sides of the range are typical glacial troughs, such as the south branch of Lake Fork, due west of Leadville, along whose smooth slope the highway leads to Carlton Tunnel without crossing even the smallest tributary valley. Evidence of glacial deposition is shown in numerous terminal and lateral moraines. Excellent examples of the former are found at the mouths of Lake Creek and Lake

[4]Fenneman, N. M., Physiography of western United States, p. 110, New York, McGraw-Hill Book Co., 1931.

Fork, the glacial deposits being directly responsible for the lake basins in each case. Lateral moraines several hundred feet high skirt the lower courses of Clear and Halfmoon creeks. Another interesting example is the huge lateral moraine of the Fryingpan glacier, west of Carlton Tunnel, described by Davis[5] and Behre,[6] which ponded the ice-free, pre-glacial tributary valleys, causing them to silt up behind the morainic ridges, forming flat-bottomed parks. Numerous other glacial features throughout the range show that it was the scene of action of many vigorous Pleistocene glaciers, which greatly increased the ruggedness of the preexisting mature topography.

General Rock Types

The rocks of this area may be grouped into four general classes: (1) pre-Cambrian crystalline rocks, (2) Paleozoic sediments, (3) Tertiary igneous rocks, and (4) Quaternary deposits.

Pre-Cambrian rocks.—The Sawatch Range is made up largely of rocks of pre-Cambrian age, later rocks being only of local importance. These older rocks include highly metamorphosed quartzite and limestone and the closely related Holy Cross and Sawatch schists of sedimentary origin, the coarse-grained Hell Gate porphyry, and two intrusive massives of variable texture and composition, which have been correlated with the Silver Plume and Pikes Peak granites of the Front Range. A more complete treatment of the pre-Cambrian rocks is given on later pages.

Paleozoic sediments.—In the field studies the contact of the pre-Cambrian rocks with the flanking sediments was generally taken as the limit of the area to be mapped, since interest was centered in the older formations. Hence little attention was given to the younger rocks beyond the determination of their relations to the underlying crystalline

[5]Davis, W. M., Glaciation of the Sawatch Range, Colorado: Bull. Harvard Mus. Comp. Zool., vol. 49, pp. 1-11, 1905.

[6]Behre, C. H., Jr., Physiographic history of the upper Arkansas and Eagle rivers, Colorado: Jour. Geol., vol. 41, p. 793, 1933.

rocks, and noting the nature of the sediments at the immediate contact. These were always found to be the basal Sawatch (Cambrian) quartzite, overlain by a succession of Ordovician, Devonian, and Mississippian limestones, sandstones, and shales, and Permo-Carboniferous red beds. These same sediments are exposed in the Mosquito Range to the east, where they have been described by others;[7] hence they will not be further treated here.

Tertiary igneous rocks.—Acidic intrusives, ranging in size from batholiths or stocks several miles in diameter to the smallest dikes and sills, are widely distributed in the Sawatch Range. They appear to be related in composition and origin,[8] and have been referred to Tertiary time.

Extrusive rocks of Tertiary age, chiefly rhyolite, occur on both sides of the Continental Divide just south of Independence Pass. A more detailed description of the Tertiary rocks is given on later pages.

Quaternary deposits.—In addition to the glacial deposits mentioned above, deposits of fluvio-glacial origin occur along the Arkansas River in certain of the terraces described by Behre.[9] Alluvial deposits were laid down in postglacial time along favorable parts of smaller streams, but are best developed along Arkansas River, where they form the lower and latest of the above-mentioned terraces. No attempt was made to differentiate these various recent deposits on the map.

PRE-CAMBRIAN ROCKS

Pre-Cambrian rocks, as indicated above, form the bulk of the Sawatch Range, and are of several different types. Each of these is briefly described below.

[7]Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geol. Survey Prof. Paper 148, pp. 25-40, 1927.

[8]Crawford, R. D., A contribution to the igneous geology of central Colorado: Am. Jour. Sci., 5th ser., vol. 7, pp. 365-388, 1924.
Stark, J. T., Heavy minerals in the Tertiary intrusives of central Colorado: Am. Mineral., vol. 19, pp. 586-592, 1934.
[9]Behre, C. H., Jr., op. cit., pp. 785-814.

Metamorphosed limestone and quartzite.—Silicified limestone, marble, and recrystallized quartzite, found interbedded with and grading into typical biotite and hornblende schists, offer the strongest evidence for the sedimentary origin of the latter. The largest area of limestone observed is exposed about 2 miles northeast of Homestake Peak, where it ranges from a dense, cherty, light-green rock to a soft sugary marble. Other metamorphosed limy sediments were noted on the slopes of Homestake Peak and along the upper course of Homestake Creek, interlaminated with biotite schist. They are easily recognized by the grooves and pits developed by differential solution along bedding planes.

A massive bed of pink quartzite is exposed in a vertically plunging fold which outlines a cirque on the southeast slope of Homestake Peak. Several feet of light-green cherty limestone is conformable with the quartzite and grades outward into typical biotite schist and injection gneiss. Thin beds or lenses of brownish quartzite are interbedded with biotite schist in the cirque directly east of Homestake Peak. Other occurrences of quartzite were found on the north slope of Lake Fork valley and near the summit of Mt. Elbert, schist being the enclosing rock in each case.

Sawatch and Holy Cross schists.—Foliated rocks, ranging from dense black biotite or hornblende schists, through banded injection gneisses, to granitoid rocks with only faint traces or "ghosts" of schist remnants, are by far the most abundant rocks of the range. These various types of foliates are everywhere gradational one into another, the type depending upon the extent to which the original metamorphosed sediments have been invaded and replaced by granitic juices, stringers, and sills from the Pikes Peak or Silver Plume massives. In extreme cases all traces of schistosity have been removed, resulting in a thoroughly granitoid rock. All outcrops which retain any evidence of original schistose character have been mapped as schist, while the larger granitoid areas, probably indigenous in part, were mapped as granite.

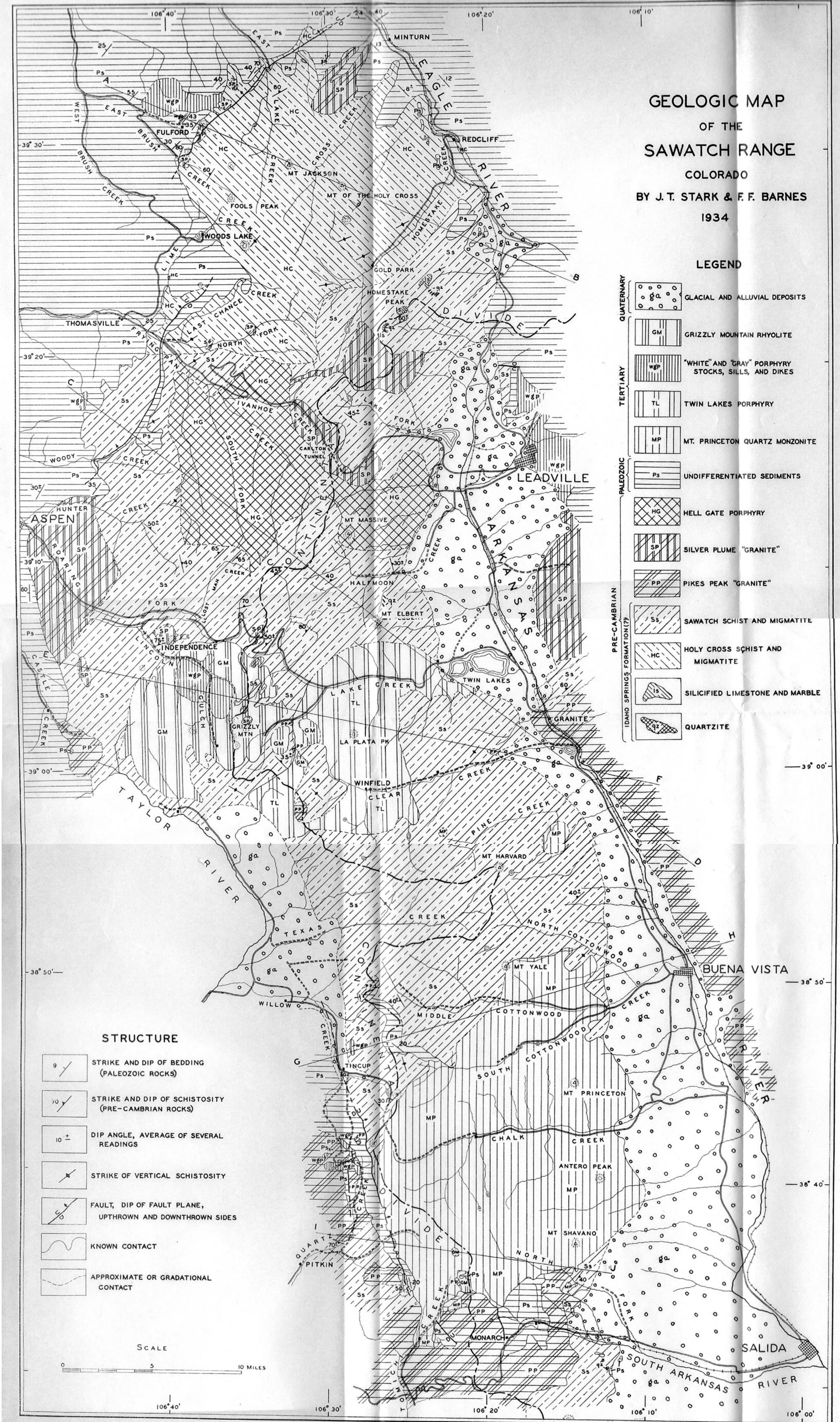
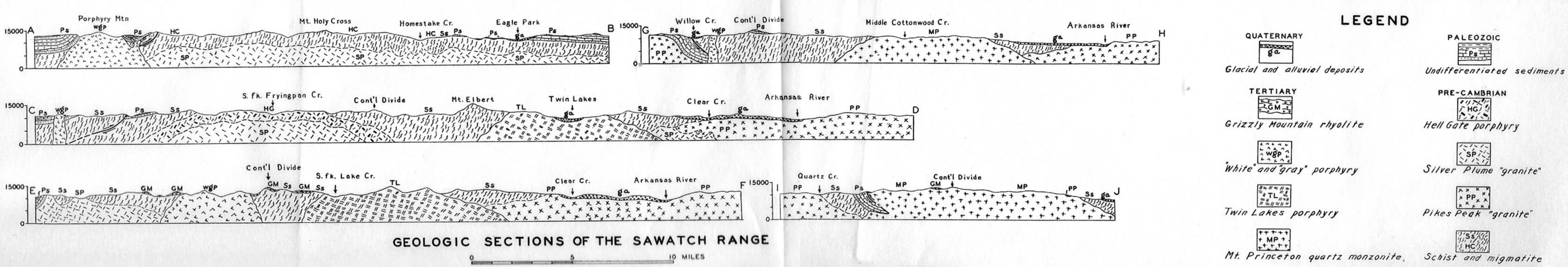


Plate I. Geologic map and sections of the Sawatch Range, Colorado.



GEOLOGIC SECTIONS OF THE SAWATCH RANGE

The Sawatch and Holy Cross schists are separated more on the basis of their field appearance than on any difference of origin or composition. The Holy Cross schist is universally and intimately injected by stringers and sills of brilliant pink pegmatite, and is distinct in appearance from the Sawatch schist, in which the pegmatite is commonly white or gray. It is not known on what the difference of color is based, since the Silver Plume massive is apparently responsible for the injection of both types of schist.

Pikes Peak granite.—Both of the pre-Cambrian massives of this area show variations in composition from place to place, apparently due to differences in the nature and quantity of materials resorbed by the very wet magmas. For convenience, the term "granite" is here used in a broad sense to embrace all these variations, including true granite, quartz monzonite, quartz diorite, and many intermediate gradations.

Rocks related to the Pikes Peak massive are confined, in the Sawatch Range, to its southern part. The northern limit, as indicated by isolated outcrops, lies between Clear and Lake creeks (latitude 39° 03′). This agrees closely with its northern limit in the Mosquito Range, where outcrops of Pikes Peak granite end just south of a point opposite the mouth of Lake Creek. Exposures of typical Pikes Peak granite are rare in the Sawatch area until the southern end of the range is reached. The rock at Monarch Pass is very similar to that exposed in the Granite Gorge of Arkansas River, below Lake Creek, which is very coarse-grained with large pink feldspar phenocrysts in a gray groundmass of quartz, feldspar and biotite. At intermediate points the granitic rocks generally contain large amounts of associated biotite and hornblende schist. Exceptions were found near Taylor Pass, 12 miles south of Aspen, and on the Continental Divide at the heads of Clear and Middle Cottonwood creeks, where small areas of homogeneous coarse granite are exposed. In the last locality, especially near Cottonwood Pass, much of the schist is intruded by and grades into masses of coarse-grained biotite-rich rock with large pink feldspars which is believed to be a migmatite of Sawatch schist and Pikes Peak granite.[10]

Silver Plume granite.—The most typical mode of occurrence of Silver Plume granite is in the form of sills in the schist, ranging from a few feet to a few hundred feet in thickness. The borders of these sills are rarely sharp, but tend to grade into the foliated rock. The granite also occurs in a few large areas in which little or no schist is found, notably east of Aspen and in the vicinity of Carlton Tunnel and the headwaters of Lake Fork. In its most typical occurrence this rock is medium coarse-grained, light-gray to pinkish-gray in color, and commonly displays a trachitoid texture due to a rough alignment of feldspar phenocrysts.

Hell Gate porphyry.—This name has been applied to a peculiar porphyritic gneissoid rock typically exposed at Hell Gate, on Ivanhoe Creek.[11] The rock is characterized by an abundance of prominent feldspar "phenocrysts" or crystalloblasts as much as an inch in length which generally show a marked parallelism. Shreds or stringers of biotite schist are also common, and in any single exposure there is always a striking agreement in the orientation of these schist remnants and the feldspar crystals. This rock was found to grade on the one hand into typical biotite schist or gneiss and on the other into equally typical Silver Plume granite. Hence it is believed that the Hell Gate porphyry merely represents a particular stage or phase of the migmatization of Sawatch schist by Silver Plume granite, but because of its distinctive appearance in the field it has been mapped separately. The probable relation of the porphyry to the schist and granite is shown in Plate I, section C-D.

Tertiary Igneous Rocks

Mt. Princeton and Twin Lakes batholiths.—Two large bodies of quartz monzonite form the core of the range in its

[10] Stark, J. T., Migmatites of the Sawatch Range, Colorado: Jour. Geol., in press.

[11] Stark, J. T., and Barnes, F. F., The structure of the Sawatch Range: Am. Jour. Sci., 5th ser., vol. 24, p. 474, 1932.

southern half. The largest of these, the Mt. Princeton batholith described by Crawford,[12] consists of a light-colored, medium coarse-grained rock, containing nearly equal amounts of quartz, orthoclase, and plagioclase, and sprinkled uniformly with biotite and minor hornblende. Ten miles to the north, the Twin Lakes batholith is exposed in the valleys of Clear and Lake creeks. This rock differs from the Mt. Princeton quartz monzonite chiefly in the presence of large phenocrysts of pink orthoclase, attaining lengths of as much as nine inches, which are so numerous and widespread as to be characteristic. Two smaller areas of similar rock have been mapped between the two batholiths and are identical in appearance with the Mt. Princeton rock, but differ in having practically no potash feldspar.

Porphyry stocks, sills, and dikes.—Intrusions of a light-gray porphyritic rock, similar in composition but finer grained than the large masses described above, are exposed near Grizzly Mountain south of Independence Pass, on the west slope of the range between Woody and Fryingpan creeks, and on Porphyry Mountain, near Fulford, in the extreme northwest corner of the area. The Grizzly Mountain stock has a fine-grained light-gray groundmass, with abundant phenocrysts of quartz and feldspar averaging 2 millimeters in diameter. This rock closely resembles and is probably to be correlated with the "gray porphyry" of the Leadville district.[13] The same is true of the smaller stock south of Fryingpan Creek.

The Porphyry Mountain stock resembles the rock at Grizzly Mountain in texture and composition, and shows interesting structural relations to the surrounding rocks (Pl. I, section A-B). This intrusion has pushed up through the surrounding Paleozoic sediments causing the latter to dip away in all directions from the igneous core. Here is def-

[12]Crawford, R. D., A contribution to the igneous geology of central Colorado: Am. Jour. Sci., 5th ser., vol. 7, pp. 367-368, 1924.

[13]Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geol. Survey Prof. Paper 148, pp. 46-51, 1927.

inite evidence, since the Permo-Carboniferous red beds took part in the deformation, that the intrusion took place since the Paleozoic—probably in Tertiary time.

Several stock-like masses of quartz monzonite porphyry and related rocks were described by Crawford[14] in the Monarch and Tomichi mining districts at the southern end of the range.

In addition to the larger masses described above, many light-colored dikes and sills corresponding to the two types of the Leadville district, the so-called "white" and "gray" porphyries, were found in all parts of the Sawatch area, ranging in thickness from a few inches to several feet. Most of these were found in the pre-Cambrian foliates, sometimes transverse but mere commonly parallel to the schistosity. A porphyry sill is well exposed at Fulford, intruded parallel to the enclosing Paleozoic sediments where they are bowed up on the east side of the Porphyry Mountain stock. This sill is similar in composition to the larger mass, and is undoubtedly related to it in origin. (See Pl. I, section A-B.) About 3 miles east of Winfield on Clear Creek a fine-grained acidic dike has been intruded along the contact between the Twin Lakes batholith and pre-Cambrian schist. At the head of Missouri Gulch, a southern tributary of Clear Creek opposite Vicksburg, a 50-foot sill of very fine-grained, light-colored porphyry with prominent quartz phenocrysts is exposed in the cirque wall, dipping 50 degrees southwest parallel to the enclosing schist. Many other sills and dikes, ranging from a very dense aplite-like rock to a medium coarse-grained gray porphyry, have been observed in many parts of the range. With the exception of the sills described at Fulford and in Missouri Gulch, all these tabular sheets appear to be nearly vertical.

Extrusive rocks.—An area of approximately 50 square miles south of Independence Pass is covered with irregular flows of gray rhyolite porphyry and minor amounts of pitch-

[14]Crawford, R. D., Geology and ore deposits of the Monarch and Tomichi districts, Colorado: Colo. Geol. Survey Bull. 4, pp. 75-85, 1913.

stone porphyry and volcanic breccia. These rocks completely surround the porphyry stock near Grizzly Mountain and may be related to it in origin. This extrusive material has been described by Howell,[15] who distinguished the gray "Grizzly Peak rhyolite" from an older lighter colored "Red Mountain rhyolite." All the evidence obtained by the writers, however, indicated that the "Red Mountain rhyolite" is merely a portion of the "Grizzly Peak rhyolite" which has been affected by mineralizing solutions. These have brought about extensive kaolinization of the feldspars, giving a lighter color to the rock, and have added finely disseminated pyrite. The subsequent oxidation of the latter is responsible for the brilliant coloration of parts of the formation, as for example on Red Mountain. In view of this evidence all this extrusive material has been mapped as a single unit and called "Grizzly Mountain rhyolite" after the most prominent peak in the vicinity. The name "Grizzly Peak rhyolite" used by Howell was discarded to avoid confusion with a mountain of that name several miles to the south. The flow structure of these lavas was best observed along the east wall of Tabor Gulch, where several irregular flows are exposed with an apparent dip of about 10 degrees to the north. Small areas of volcanic breccia, bearing a strong resemblance to that around Grizzly Mountain, were mapped by Crawford[16] and observed by the junior author near the head of Tomichi Creek. These extrusive rocks are probably contemporaneous with at least part of the San Juan eruptives south of the Sawatch Range.

Structure

The structure of the central and northern parts of the Sawatch Range was described by the writers in an earlier paper.[17] Since that time the mapping has been carried far-

[15]Howell, J. V., Twin Lakes district of Colorado: Colo. Geol. Survey Bull. 17, pp. 59-69, 1919.

[16]Crawford, R. D., Geology and ore deposits of the Monarch and Tomichi districts, Colorado: Colo. Geol. Survey Bull 4, 1913.

[17]Stark,, J. T., and Barnes, F. F., The structure of the Sawatch Range: Am. Jour. Sci., 5th ser., vol. 24, pp. 471-480, 1932.

ther south and a second paper[18] published by the senior range. Hence only a brief resume of the structure need be author on the reverse faulting on the west slope of the given here.

Folding.—The Paleozoic sediments are upturned along the flanks of the pre-Cambrian core and strike in general parallel to the present northward trend of the range. This anticlinal doming, which was recognized by early writers,[19] was probably associated with Laramide diastrophism. Emmons[20] believed the Sawatch Range to have been an island in the Paleozoic seas. This theory is opposed by the general absence of overlap along the pre-Cambrian contact (the overlying formation in every exposure being the Cambrian quartzite), and by the finding of lower Paleozoic sediments at an elevation of 13,000 feet on the crest of the range west of Buena Vista.

An earlier structure is exhibited in the pre-Cambrian schist. In the northern part of the range this structure consists of tightly compressed isoclinal folds striking N. 60° to 65° E., with axial planes overturned and dipping steeply to the northwest. This general structure is clearly recorded in the many drag folds which are well developed throughout the schist. In the southern part of the range there is a change in the direction of these old structural lines: followed southward they swing gradually from northeast through north to northwest. This change of strike agrees with a similar change in the trend of post-Cambrian thrust faults along the western flank of the range, suggesting a genetic relation between the old and later structural lines.[21]

Faulting.—In the paper just cited the senior author described reverse faults along the western slope of the range.

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[18]Stark, J. T., Reverse faulting in the Sawatch Range: Geol. Soc. America Bull., vol. 45, pp. 1001-1016, 1934.

[19]Hayden, F. V., U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, pt. 1, pp. 39, 49, 1874.
Peale, A. C., U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, pt. 1, p. 246, 1874.

[20]Emmons, S F., Orographic movements in the Rocky Mountains: Geol. Soc. America Bull., vol. 1, pp. 259-264, 1890.

[21]Stark, J. T., Reverse faulting in the Sawatch Range: Geol. Soc. America Bull., vol. 45, p. 1013, 1934.

These faults, which are recognized with difficulty in the pre-Cambrian complex, are clearly recorded in the flanking sediments. On the east slope, glacial deposits and terrace gravels of Arkansas Valley mask most of the eastward dipping sediments.

Three low angle thrust faults have been mapped as shown on Plate I. In each case pre-Cambrian granite or schist has been thrust over Paleozoic sediments. The fault planes are nearly parallel to the bedding where exposed, but are somewhat steeper and locally cut across the strike. In the two northern faults, the East Lake Creek and Biglow thrusts, the general strike is northeast with dip to the northwest. In the southern (Tincup-Graphite Basin) thrust the strike is to the northwest and dip to the northeast. The thrusting in each case has been up the dip of the sediments—from the northeast in the south and from the northwest in the north.

In many places along the fault zones the dips of the sediments and fault planes steepen to nearly vertical on the downthrow side of the thrusts. Slickensides and small shear zones on the downthrow sides suggest uplift on this side subsequent to the thrusting. In some cases reversal of movement is recorded along the old thrust planes. Uplift following the thrusting is also suggested by a nearly vertical normal fault in the west wall of Quartz Creek, the upthrow side of this fault being the downthrow side of the Tincup-Graphite Basin thrust.

That the reverse faulting occurred before the intrusion of the Mt. Princeton (Tertiary) batholith is indicated by the fact that the latter cuts and partly obliterates the fault planes in places north and south of Middle Quartz Creek. (See Plate I, section I-J.) It is not improbable that the uplift responsible for the steepening of dips on the downthrow side of the thrusts followed the Tertiary intrusions and represents a late phase of Laramide diastrophism or even post-Laramide uplift.