CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1926

PART I. METALS AND NONMETALS EXCEPT FUELS

RECENT DEVELOPMENTS IN THE ASPEN DISTRICT, COLORADO

By ADOLPH KNOPF

INTRODUCTION

The Aspen district of Colorado was mapped and studied with great detail and thoroughness in 1895 by J. E. Spurr, who made it the subject of a well-known monograph.[1]

With the lapse of 30 years mining in the area surveyed by Spurr has come to a standstill. During the last decade, however, much exploratory work has been done in the vicinity of Richmond Hill, a little farther south, and public demand has consequently arisen for a southward extension of the early survey. In response to this demand the writer was instructed by the United States Geological Survey to visit the district, and he did so in July, 1923. The only topographic base map available was on a scale of 1:62,500 (about 1 mile to the inch), a scale too small for representing the geology in as much detail as on Spurr's main map (scale 1:9,600, or 800 feet to the inch), or his maps of the more productive areas (scale 1:3,600, or 300 feet to the inch). The complicated geology shown on Spurr's maps continues southward and has been mapped by the writer in the vicinity of the Little Annie mine, or Richmond Hill. Plate 1 is a composite geologic map in which Spurr's work is supplemented by that of the writer.

The principal contributions in this brief report are descriptions of the recent mining developments in the southern part of the district, the correlation of the occurrence of ore in the Richmond Hill area with geologic structure, the account of the relation of oxidation

[1] Spurr, J. E., Geology of the Aspen mining district, Colo.: U. S. Geol. Survey Mon. 31, 1898.

of the ores to glacial history, and a more detailed discussion of the igneous geology, which is considerably more complex than has hitherto been thought.

THE ASPEN MONOGRAPH

The public demand for a resurvey of the Aspen district was in essence a strong tribute to the great practical usefulness of the Aspen monograph, by J. E. Spurr. In no other district in the writer's acquaintance has the local geology become so thoroughly part and parcel of the working knowledge of the mining population as at Aspen. "Cambrian quartzite," "Silurian dolomite," "Weber shale" are everyday terms among these men, and the stratigraphic and lithologic significance of the terms are fully understood. The accuracy and the detail of the geologic maps accompanying the monograph have made them often do service in determining the exact location of the portals of mining tunnels that were to be driven. Some of these tunnels have been driven along the cross sections shown in the Aspen monograph and have verified the geologic conditions depicted in the cross sections. Occasionally long tunnels have been run to intersect ore at depth, as at the Newman tunnel, in defiance of the geologic conditions shown in the cross sections, and the result has been that much money was unnecessarily expended.

One element in the long-continued usefulness of the Aspen monograph has been the complete representation of the complex faulting that has affected the rocks of the district. Because the deposition of the ore bodies was controlled in a remarkable way by the faults, the geologic maps showing these faults have proved to be particularly useful in the search for undiscovered ore.

On the other hand, the theoretical conclusions as to the origin of the ore-depositing solutions, a problem that looms so large in current discussions of ore genesis, have had little practical bearing. At the time of writing the Aspen monograph Spurr sought to show that the ores were deposited from hot-spring waters—meteoric waters that had sunk from the earth's surface and become heated by coming into contact with a body of hot igneous rock—and the hot-spring waters of Glenwood Springs, 40 miles away, were cited in analogy. His views on this problem have changed or been modified several times since, but their practical importance as an aid in finding ore remains far behind that of the objective presentation of the areal and structural geology given in the Aspen monograph and its atlas.

It is somewhat surprising, after scanning the geologic maps of the Aspen district, to find in the field that much of the district is deeply covered with glacial drift and that consequently much of the bedrock is completely concealed. Smuggler Mountain is a striking example of this state of affairs. From the highly detailed geologic maps it would not be suspected that there are but one or two outcrops of bedrock on the mountain. The bedrock geology of Smuggler Mountain as shown on the maps was extrapolated to the surface from exposures in prospect pits, shafts, and mine workings, and this same procedure was followed throughout the district. None of these openings are now accessible, and geologic maps showing detail equal to that of the maps in the Aspen monograph could not be made from the data available in the field. The policy of ignoring the covering of glacial drift was of the highest practical utility, in that it plainly indicated the places at the surface favorable for exploratory work.

OUTPUT

The total value of the output of the Aspen district from 1880 to 1922, inclusive, as estimated by C. W. Henderson, of the United States Geological Survey, is nearly $100,000,000, almost wholly in silver and lead.

The detailed figures of the output of metals in Pitkin County, from 1880 to 1922, inclusive, as assembled by Mr. Henderson after an exhaustive inquiry, are $577,930 in gold; 97,641 ounces of silver, valued at $72,988,357; 1,128,463 pounds of copper, valued at $197,443; 562,582,702 pounds of lead, valued at $25,573,729; and 16,377,002 pounds of zinc, valued at $1,028,289; total value, $100,365,748. The gold can not be credited to Aspen, but the remainder of the output of the county has come almost entirely from Aspen.

The production attained its maximum in 1892, when the value of the output reached nearly $8,000,000. The next year, however, it fell to $4,500,000, and by 1908 the value of the yearly output had fallen below the million-dollar mark. It fluctuated around that figure, with some increase during the war years, until 1921. In that year a further severe decline occurred, which has been greatly accentuated by the practical cessation of mining in 1923.

GENERAL GEOLOGY

PRE-CAMBRIAN GRANITE AND THE OVERLYING PALEOZOIC SEDIMENTARY ROCKS

The basement rock of the district is a massive granite of pre-Cambrian age. It is a fairly coarse light-pink variety containing both muscovite and biotite; the white mica is the more abundant. This muscovite appears as detrital flakes in a number of the overlying formations and thus indicates that the granite was exposed to erosion in adjacent regions at different times.

On the granite rests a conformable series of sedimentary beds, the descriptive details of which may be found in the Aspen monograph. The formations extending up to and including the Maroon formation, which are those of main interest because they underlie the productive part of the district, aggregate 6,200 feet in thickness. Their sequence and general features are shown in Figure 1. The identification of the sedimentary formations at Aspen and the establishment of their sequence are the results of the work of Lakes, S. F. Emmons, Brunton, Henrich, Newberry, and Spurr, as shown by Girty.[2]

The Sawatch quartzite, or Cambrian quartzite, as it is invariably called in the district, overlies the granite. It is a hard vitreous white rock. The basal beds are obscurely cross-bedded and locally are current rippled; and as the top beds also are cross-bedded it is evident that the whole Cambrian section was laid down in a shallow sea. The Cambrian is succeeded by thin-bedded dolomite, designated "Lower Silurian" in the Aspen monograph but now referred to the Ordovician—a mere change in terminology, however, Ordovician being the name adopted to replace "Lower Silurian" of early usage. Locally this formation is always called the "Silurian dolomite." In the Aspen monograph it was designated the Yule formation, but it represents only the lower part of the typical Yule limestone. Above this dolomite is the "Parting" quartzite, which was thought by Spurr to be Devonian but is believed by Girty,[3] on cogent evidence, to be Ordovician, and which is now treated as a member of the Yule limestone. The Leadville limestone lies above the "Parting" quartzite and is divided into a lower dolomite member and an upper pure limestone member. The upper member is the blue limestone, which, as is well known, has been preeminently the ore-producing rock at Aspen, as well as in other districts in Colorado. The Leadville limestone is overlain by the black shales and thin-bedded limestones designated Weber formation in the Aspen monograph and Weber (?) formation in this report, because they are now generally regarded as probably not equivalent to any part of the typical Weber quartzite of Weber Canyon, Utah. The name Weber is, however, here retained, with a question mark, for the convenience of the mining public, which has long known these rocks under that name. The Weber (?) formation as here mapped corresponds to only the lower part of the rocks to which the name Weber has been applied in the Leadville and other districts of central Colorado—that is, to the rocks designated in earlier reports "Weber shales," the equivalent of the overlying "Weber grits" of

[2] Girty, G. H., The Carboniferous formations and faunas of Colorado: U. S. Geol. Survey Prof. Paper 16, pp. 15–17, 52–53, 1903.

[3] Idem, p. 161.

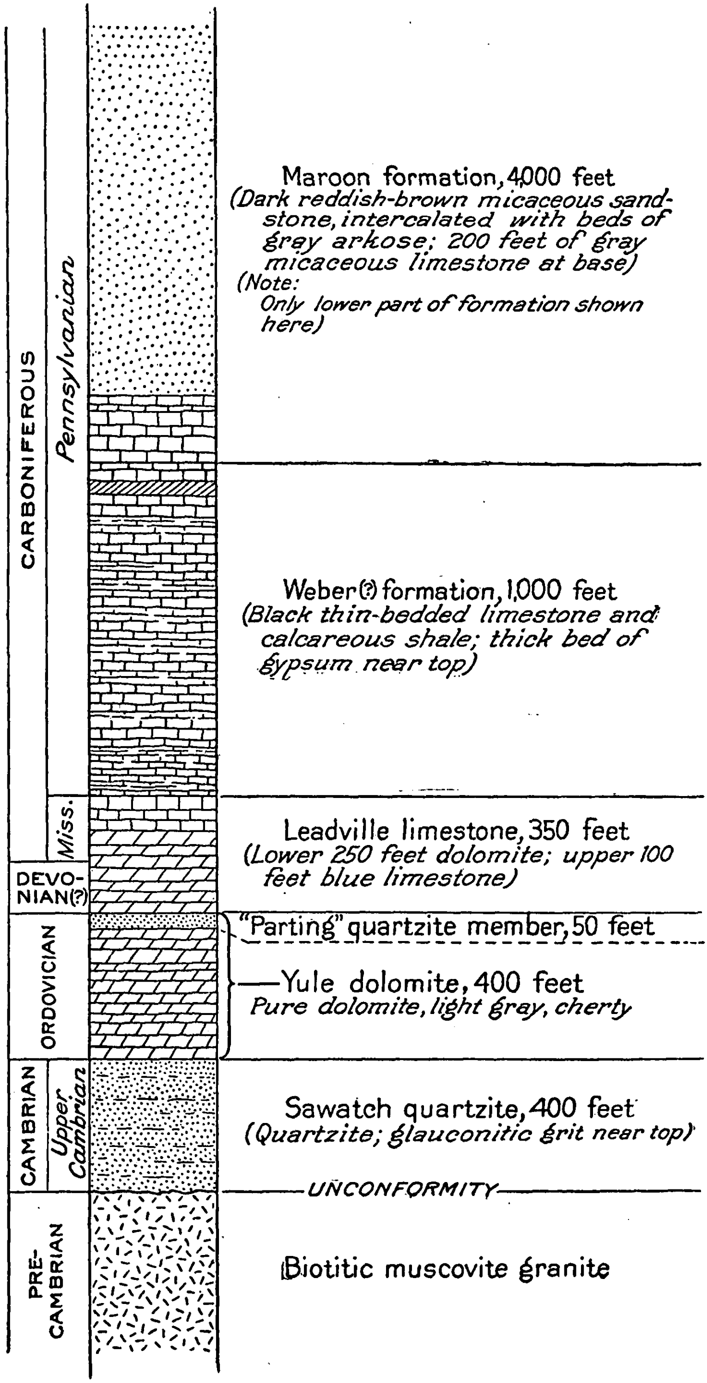


FIGURE 1.—Generalized columnar section of Carboniferous and older rocks in the Aspen district, Colo. Stratigraphic units as defined in Aspen monograph; names and lithologic designations modified to conform with present usage.

the Leadville and other districts being included in the Maroon formation as mapped by Spurr in the Aspen district. The Maroon formation grades imperceptibly upward into a great series of thick-bedded brick-red sandstone, possibly of Triassic age.

The earlier Paleozoic formations, as will be seen from a glance at the stratigraphic column of Figure 1, are comparatively thin and are of distinctive rock composition. They therefore lend themselves readily to determining the faults which have profoundly dislocated them and which are of so great economic importance because of their influence on the occurrence of ore. As the younger formations—the Weber (?) and the Maroon—are much thicker and lack distinctive members, it is difficult to determine the faulting that has affected them. They are shown in the Aspen monograph as comparatively undisturbed, but, as is perhaps most obvious in the long tunnels driven in the southern part of the district, they have been as severely dislocated by faults as the older formations.

At the end of Cretaceous time or early in the Eocene these rocks together with overlying Mesozoic formations now removed by erosion in the area shown in Plate 1, were intruded by igneous rocks, folded, and complexly faulted. Along the faults thus produced were deposited the ores that have made the district so productive.

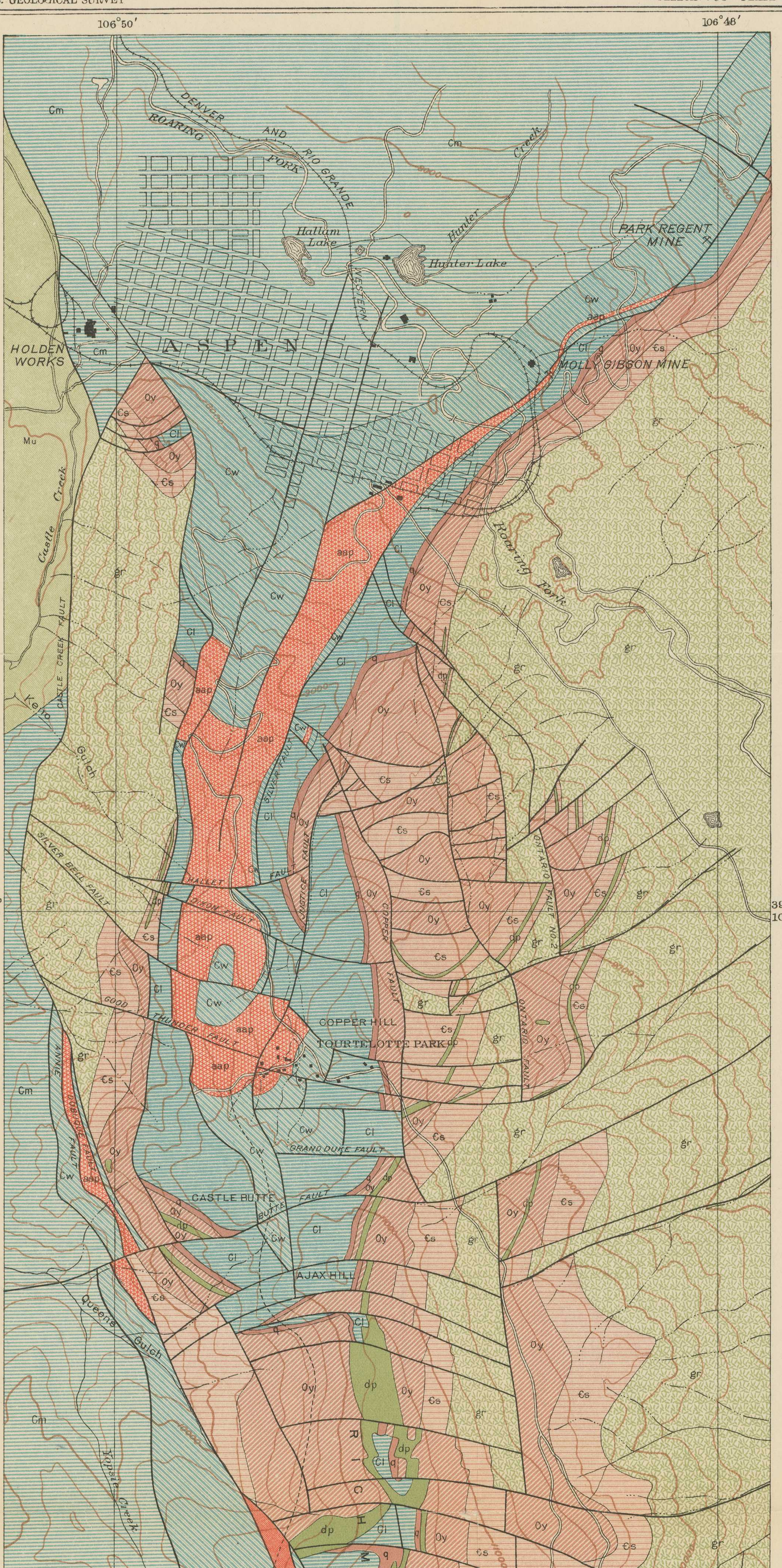
INTRUSIVE IGNEOUS ROCKS

GENERAL FEATURES

Diorite porphyry and quartz porphyry were the only intrusive igneous rocks recognized by Spurr in the Aspen district. However, the quartz porphyry masses that he mapped prove to include three distinct rocks, and the description given in the Aspen monograph represents a composite of these three. They are here termed albite aplite porphyry, albite alaskite porphyry, and aplite. In spite of certain marked differences they are evidently closely related, as indicated by their large content of albite. The aplite appears to be the youngest, for it cuts through a sill of the alaskite porphyry.

Granodiorite porphyry is another variety of intrusive igneous rock found in the Aspen district, occurring just south of the area mapped by Spurr. It is probably related in origin to the great bodies of intrusive granodiorite that appear in the Elk Mountains at the head of Castle Creek, south of Ashcroft; in fact, inasmuch as it differs but slightly from the granodiorite and only in respect to texture, its occurrence suggests that a mass of granodiorite underlies the Aspen district at some depth.

Because of the importance attached to igneous rocks in current theories of the origin of ore deposits, the intrusive igneous rocks are here described in some petrographic detail, though briefly.



EXPLANATION

SEDIMENTARY ROCKS

Mu — Undifferentiated Mesozoic rocks

CARBONIFEROUS

Pennsylvanian

Cm — Maroon formation
(Dark reddish-brown micaceous sandstone, intercalated with beds of gray arkose (grit); at base 200 feet of gray micaceous limestone. As here mapped includes the equivalent of the "Weber grits," which in the Leadville district are included in the Weber (?) formation)

Cw — Weber (?) formation
(Black shale and thin-bedded limestone Thick gypsum bed near top)

Mississippian

Cl — Leadville limestone
(Upper 100 feet blue limestone; lower 250 feet dolomite. Lower part may be of Devonian age) ?

ORDOVICIAN

q, Oy — Yule dolomite
(Pure dolomite, thin bedded, light gray, and cherty, with "Parting" quartzite member, q, at top)

CAMBRIAN

Upper Cambrian

€s — Sawatch quartzite
(Chiefly quartzite; glauconitic grit near top. Unconformable on pre-Cambrian granite)

IGNEOUS ROCKS

CRETACEOUS OR TERTIARY

Late Cretaceous or early Eocene

gdp — Granodiorite porphyry

a — Aplite

aap — Albite aplite porphyry

ap — Albite alaskite porphyry

dp — Diorite porphyry

PRE-CAMBRIAN

gr — Biotitic muscovite granite

Fault

A. HOEN & CO. BALTIMORE, MD.

Scale, 3 inches equals 1 mile
0 1/4 1/2 1 Mile

Geology by J. E. Spurr and A. Knopf

GEOLOGIC MAP OF THE ASPEN DISTRICT, PITKIN COUNTY, COLORADO

The igneous rocks, with the probable exception of the granodiorite porphyry, were all injected before the powerful folding and faulting that dislocated the rocks of the Aspen district and before the ores were deposited. They were doubtless intruded during the Laramide revolution, in late Cretaceous or early Eocene time. The diorite porphyry, being the most basic rock in the district, was probably the earliest, in conformity with the general rule that the more basic rocks are injected before the more siliceous varieties. It was followed by albite alaskite porphyry, which is peculiarly distinguished by its sporadic stout prisms of muscovite, and this in turn was followed by albite aplite porphyry, which is especially conspicuous as forming the great sill in Tourtelotte Park, and by almost felsitic aplite, which is without doubt the nonporphyritic finer-grained equivalent of the aplite porphyry. These three last-named rocks represent injected masses of highly differentiated magma, which were doubtless squeezed out from a deep-seated source at slightly different stages during the course of differentiation.

The granodiorite porphyry, which was not known to Spurr, was probably intruded after the epoch of folding and faulting and is therefore the youngest igneous rock in the district.

DIORITE PORPHYRY

Diorite porphyry occurs as a sill in the Paleozoic rocks; near Aspen it is in contact with the basement granite, but toward the south it rises gradually, cutting at a narrow angle across the beds, until at Richmond Hill and Lime Gulch it lies above the Leadville limestone and is overlain by Weber (?) shale. As it rises southward it increases in thickness from 15 feet to more than 300 feet on the ridge on the south side of Lime Gulch. It is particularly abundant on the west slope of Richmond Hill and at the head of Lime Gulch, where its extensive exposure is in part due to repetition by faulting.

The diorite porphyry is a dark fine-grained rock, and as it is not obviously porphyritic, it resembles a finely granular diorite. Its most distinctive feature is that it is spotted black by sporadic phenocrysts of hornblende or its alteration products. It is a rock of marked individuality and is easily distinguishable from any of the other intrusive rocks of the district. On Richmond Hill it is liberally spotted with small areas of yellowish-green epidote, as well as by the dark spots of altered hornblende.

Under the microscope the diorite porphyry from Richmond Hill is seen to consist of feldspar phenocrysts, now completely altered to epidote except where rarely the peripheral zone of albite has remained intact, and ferromagnesian phenocrysts, largely chloritized, embedded in a microgranular groundmass of quartz and albite. The feldspar of the groundmass is fresh and clear, thus contrasting notably with that of the phenocrysts; it has evidently escaped alteration to epidote, like the peripheral zones of some of the plagioclase phenocrysts, because of its albitic, noncalcic composition. From the abundance of chlorite in the rock, the diorite porphyry was evidently a fairly basic variety, much more basic than any of the other igneous rocks in the district.

ALBITE ALASKITE PORPHYRY

The albite alaskite porphyry is a striking rock, of much local interest in the southern part of the Aspen district because the ore body of the Little Annie mine occurred in the Weber (?) formation just above the upper contact of a steeply inclined sill of this porphyry. The porphyry is a white microgranular rock carrying sporadic hexagonal prisms of muscovite, abundant prominent phenocrysts of quartz, and numerous inconspicuous phenocrysts of feldspar. The muscovite prisms, which are blackish because of their length and therefore resemble biotite, are a particularly distinctive feature of the alaskite porphyry and are uniformly distributed throughout the rock, occurring in full size even up to the very edges of the chilled contacts of the porphyry against the inclosing Weber (?) shale. The muscovite prisms are evidently early (intratelluric ?) separations from the magma.

The alaskite porphyry mass of main economic interest is the sill at the Little Annie mine and the faulted extensions of the sill both north and south of the mine. (See pl. 1.) It varies greatly in width from place to place, being as much as 1,000 feet wide on the north side of Winnie Gulch and narrowing to a point a thousand yards farther north, owing to the convergence of the faults that bound it; and, in general, the notable variations in width appear to be similarly due in the main to the effects of faults. The sill is well shown in the workings of the Hope tunnel, where it is 340 feet thick, in the Midnight tunnel, in the Jewell prospect, and in Lime Gulch. Wherever seen it appears to have been injected parallel to the strike and dip of the inclosing Weber (?) formation. At one point in the Midnight tunnel it is accompanied by a parallel subsidiary sill, 2 feet thick, which lies 50 feet above it. Another sill or dike of the porphyry occurs near the Eva Bell shaft; it is in the Weber (?) formation, 300 feet below the overlying Maroon formation. Other masses are common west of the Jewell shaft, but they are not well exposed.

The largest mass of the alaskite porphyry is near the south end of Richmond Hill, where it extends from the head of Lime Gulch eastward across the divide. It forms a roughly elliptical stock which breaks through the pre-Cambrian granite and the overlying Paleozoic strata as high as the blue limestone of the Leadville formation.

Under the microscope the feldspar phenocrysts of the alaskite porphyry are found to be fairly abundant, much more so than the quartz crystals that are so conspicuous to the unaided eye. They prove to be a nearly pure albite. As they are referred to in the Aspen monograph as orthoclase, it is perhaps necessary to give the diagnostic properties determined concerning this feldspar: Multiple twinning with maximum symmetrical extinction of 20°, optically positive, birefringence 0.010, refractive indices less than 1.54. The euhedral hexagonal phenocrysts of mica, generally 0.1 inch in thickness, are found to be muscovite, as proved by their colorlessness and wide axial angle. The occurrence of muscovite phenocrysts in porphyry is highly unusual, and its presence in alaskite porphyry in other Colorado districts has been pointed out by Spurr, Garrey, and Ball.[4] It was first established by Cross to occur in Colorado in the "White" porphyry at Leadville.

The phenocrysts of albite, quartz, and muscovite are set in a coarsely micrograinitic groundmass of quartz, the more abundant constituent, and lamellated albite. Secondary constituents, muscovite and carbonate, either calcite or dolomite, are abundant and have developed at the expense of both the albite of the phenocrysts and that in the groundmass.

This porphyry was called quartz porphyry by Spurr; it is the only one at Aspen to which that name is at all applicable, but the term is now obsolescent. In 1908 he referred to it as an alaskite porphyry,[4] but in 1909 he termed it a rhyolite porphyry,[5] without, however, realizing that he was including three distinct intrusive rocks under that designation. As this porphyry gives no evidence of having been related to the extrusion of any surface volcanic rock and as in its textural development and content of muscovite phenocrysts it shows clearly that it is a closely allied differentiate of a deep-seated intrusive rock, the name alaskite porphyry will be retained, and to signalize that its feldspar content is wholly albite instead of the more usual orthoclase it will be called an albite alaskite porphyry.

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[4] Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic geology of the Georgetown quadrangle, Colo.: U. S. Geol. Survey Prof. Paper 63, pp. 132–133, 1908.

[5] Spurr, J. E., Ore deposition at Aspen, Colo.: Econ. Geology, vol. 4, pp. 305–306, 1909.

ALBITE APLITE PORPHYRY

The albite aplite porphyry is most prominently represented by the great homogeneous sill in Aspen Mountain, which extends southward into Tourtelotte Park. This sill is about 300 feet thick and has been intruded near the base of the shale of the Weber (?) formation, thus lying above the horizon at which the diorite porphyry sheet occurs. As the two rocks are nowhere in contact, their relative ages are undetermined.

This rock is a gray porphyry, pure white where unweathered, carrying somewhat inconspicuous phenocrysts of striated feldspar, 0.1 to 0.2 inch in diameter, which are embedded in a nearly phanerocrystalline groundmass. It was mapped as quartz porphyry by Spurr, but it does not show the quartz phenocrysts which according to that designation might be expected to occur.

Specimens obtained near the portal of the Veteran tunnel, at Aspen, and near the Best Friend shaft, in Tourtelotte Park, are essentially alike in their general features. The phenocrysts are found to be polysynthetically twinned albite ($Ab_{96}An_4$), although specifically referred to by Spurr[7] as orthoclase. The groundmass is made up of polysynthetically twinned albite and quartz, the fabric ranging from microgranitic to panidiomorphic. In the specimen from Tourtelotte Park much of the quartz of the groundmass is remarkably idiomorphic. No satisfactory name is available to apply to this rock, so in order to signalize its more important features it will be termed an albite aplite porphyry. It differs markedly from the alaskite porphyry in not containing phenocrysts of muscovite and quartz.

The porphyry has been much altered by ore-forming solutions, as shown by the abundant sericite, pyrite, and ferriferous dolomite that have been developed in it. The oxidation of the secondary iron minerals has given much of the rock a speckled appearance.

APLITE

Aplite occurs as a thick dike in the southern part of the district. So far as known to the writer, it extends only a short distance into the area mapped by Spurr, who did not distinguish it from the quartz porphyry with which it is there associated. It is well shown in the workings of the Hope tunnel, where it cuts through the alaskite porphyry dike. The same aplite dike is well shown on the north side of Lime Gulch, where it is 300 feet thick and lies just under the alaskite porphyry sill, which dips 70° W. and is separated from it by only 3 feet of metamorphosed black shale.

[7] Op. cit. (Mon. 31), p. 50.

The aplite is a white or cream-colored rock without porphyritic crystals, fine grained, almost verging on the felsitic in appearance. At contacts it has in fact been chilled to a felsite with almost imperceptibly faint flow structure.

Under the microscope a few "microphenocrysts" of albite become apparent, set in a panidiomorphic groundmass of albite and quartz. The quartz is abundant, and much of it occurs as sharp dihexahedrons. The texture is typical of aplite, and as the rock contains no orthoclase it is here termed an albitic aplite. Sericite is generally abundant as a secondary product.

GRANODIORITE PORPHYRY

The two stocks of granodiorite were found during the present work to be intrusive into the Maroon formation southwest of the Little Annie mine. The larger and more conspicuous mass is well exposed in prominent cliffs along the canyon of Little Annie Creek; the other mass is half a mile to the south. The porphyry in appearance practically resembles a medium-grained quartz diorite, although much of the quartz, unlike that of a normal quartz diorite, occurs as distinct porphyritic crystals.

Andesine ($Ab_{55}An_{45}$), quartz, and biotite are the phenocrysts; they are closely set in a groundmass that is a remarkably well-developed micrographic intergrowth of orthoclase and quartz in the porphyry of Little Annie Creek and is a hypidiomorphic granular aggregate of plagioclase, orthoclase, and quartz in the other porphyry mass. On the basis of their phenocrysts these rocks would be named quartz diorite porphyry, but on the basis of bulk composition, which is obviously like that of the granodiorite at the head of Castle Creek, in the Elk Mountains, south of Aspen, they would be termed granodiorite porphyry, and this name is adopted in order to emphasize their probable genetic relation to the granodiorite in the Elk Mountains.

GRANODIORITE

The mass of intrusive plutonic rock nearest to the Aspen district occurs in the Elk Mountains, on the headquarters of Castle Creek, 12 miles south of Aspen, near the old mining camp of Ashcroft. This mass is the northward extension of the great body mapped by Cross as making up the Sawtooth Range of the Elk Mountains, in the Anthracite and Crested Butte quadrangles; it was termed by him diorite. From his description of the rock it is apparent that it would now be termed a granodiorite. Where seen by the writer, on the road to the Montezuma mine, it conforms closely to the description given by Cross. It is a homogeneous body of clear-gray fresh-looking fine-grained granodiorite, of light color, because it carries only sparse biotite.

Microscopically, the granodiorite is found to consist dominantly of andesine ($Ab_{54}An_{46}$), together with quartz, orthoclase, and biotite, named in the order of decreasing abundance. The rock is of normal granitic texture and is therefore a biotite granodiorite.

The granodiorite has exerted a powerful, widespread metamorphic effect on the rocks of the Maroon formation, which it has invaded—the cement in the arkose has been altered to epidote, the argillaceous beds have been converted into biotite hornfels, and the calcareous beds into calc hornfels, such as the epidote-scapolite-titanite hornfels in the vicinity of the mill of the Montezuma mine, near the head of Castle Creek. This marked metamorphism indicates, as Cross long ago pointed out, that the granodiorite magma contained such mineralizing agents as fluorine and chlorine at the time of its intrusion.[8] Contact-metamorphic magnetite deposits are associated with the granodiorite at Taylor Peak, 15 miles south of Aspen, and have been described by Harder.[9] At Snowmass Peak, 15 miles west of Aspen, and at Mount Sopris, 20 miles northwest of Aspen, similar granodiorite evidently occurs, as reported by S. F. Emmons.[10]

The granodiorite, according to Cross,[11] is of Eocene or later age. It was intruded after the folding of the Cretaceous rocks, as shown by structure section B–B on the Crested Butte geologic map.

IGNEOUS ROCKS OF PORPHYRY MOUNTAIN

At Porphyry Mountain, 14 miles north of Aspen, on the northward extension of the Aspen mineral belt, is a large intrusive mass of porphyritic aplite. It is an irregularly crosscutting body about 1,000 feet wide, but its major dimension is in the direction of the bedding of the steeply tilted sedimentary rocks that inclose it. Along its periphery, in the inclosing Leadville limestone, occur a few small contact-metamorphic deposits composed of garnet and magnetite.

It is a white rock of sugary texture and is inconspicuously and sparsely porphyritic through the presence of scattered phenocrysts of feldspar and flakes of biotite. Under the microscope the phenocrysts are seen to comprise albite and orthoclase and to be embedded in a panidiomorphic matrix of albite, orthoclase, and quartz; much

[8] Cross, Whitman, The laccolitic mountain groups of Colorado, Utah, and Arizona: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, pp. 180, 230, 1894.

[9] Harder, E. C., The Taylor Peak and White Pine iron-ore deposits, Colo.: U. S. Geol. Survey Bull. 380, pp. 188–194, 1909.

[10] U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (No. 9), p. 2, 1894.

[11] Idem, p. 5, and legend of geologic map of Crested Butte quadrangle.

of the quartz is sharply euhedral. Porphyritic aplite seems the most appropriate designation for this rock. It evidently has close affinities with the albite aplite porphyry at Aspen. It is far better preserved, having been much less altered by the action of mineralizing solutions.

In addition to the porphyritic aplite, there occurs at Porphyry Mountain a sill of granite porphyry, the lower contact of which is being prospected by the Aspen Silver Lead Mines Co. This porphyry is crowded with phenocrysts of quartz, feldspar (mainly orthoclase), and biotite, which are inclosed in an aphanitic groundmass. It does not resemble any porphyry that occurs elsewhere in the Aspen district.

CORRELATION OF THE IGNEOUS ROCKS

The igneous rocks in the region east of Aspen, which were intruded at the end of the Cretaceous or beginning of the Tertiary period, have recently been described by Crawford.[12] The sequence of events deduced by him is as follows: (1) Intrusion of porphyries from great depth; (2) large-scale folding and faulting; (3) intrusion of quartz diorite in small bodies throughout a wide region; (4) invasion by granodiorite or quartz monzonite batholiths; (5) minor faulting; (6) deposition of minerals that emanated from the quartz monzonite magma; (7) a second intrusion of porphyries; (8) more faulting.

This sequence is a generalized statement that applies to the region as a whole, and it is improbable that the full succession of events has occurred in every district or even that the events have occurred everywhere in the same order. The logically most secure procedure demands that the sequence of events be determined locally for each district as well as may be, because the supplementing of an incomplete local history by evidence obtained from distant areas is inherently more or less hypothetical.

The established sequence at Aspen is as follows: (1) Intrusion of diorite porphyry, alaskite porphyry, aplite porphyry, and aplite, the order of arrival being unknown from field evidence except that the aplite cuts the alaskite porphyry and is therefore the younger of the two; (2) folding and faulting; (3) deposition of ore; (4) more faulting. The time of intrusion of the granodiorite porphyry is not fully known from the local evidence; but if the granodiorite porphyry is the more rapidly cooled equivalent of the granodiorite in the Sawtooth Range of the Elk Mountains, as appears highly probable from their identity of composition, then it was intruded after

[12] Crawford, R. D., Contribution to the igneous geology of central Colorado: Am. Jour. Sci., 5th ser., vol. 7, pp. 365-388, 1924.

the folding and is accordingly the youngest igneous rock in the Aspen district. The sequence of events at Aspen is accordingly in the main like that in the districts east of Aspen as given by Crawford. Spurr, on the other hand, correlated the diorite porphyry of Aspen with the granodiorite ("diorite") of the Elk Mountains,[13] but this correlation appears to be erroneous, because the rocks are unlike in composition and because the diorite porphyry was intruded before the epoch of powerful folding and faulting and the granodiorite was intruded after the epoch of folding.

Spurr believes that the marked doming up of the rocks at Aspen, amounting to 5,000 feet at the center of greatest uplift, was the result of a "very local uplift, such as would arise from a vertically exerted force."[14] To account for this remarkable feature of the district "it was reasoned out that this domal uplift was due to the upward propulsion of a column or pipe of molten igneous rock, which never reached the surface." Possibly the stocks of granodiorite porphyry in the southern part of the district are the tops of cupolas on an underlying body of granodiorite, whose emplacement domed up the rocks in the productive part of the Aspen district in the way described by Spurr.

THE ORE BODIES

GENERAL FEATURES

The ore bodies of the Aspen district are silver-bearing lead deposits that have been formed mainly through the replacement of limestone. Most of the ore bodies were situated along one or the other of two faults, both of which are essentially parallel to bedding planes—the Silver fault, between the Leadville limestone and the overlying Weber (?) formation and the Contact fault, which separates the dolomite member of the Leadville formation from the overlying blue limestone. Particularly large ore bodies occurred where the Silver or Contact faults were cut by cross faults. So well is this mode of occurrence of the ore understood and so much more readily are faults found at the surface than outcrops of ore bodies, that the usual method of exploring for new ore bodies is to drive tunnels for such intersections, regardless of whether ore is known to occur at the surface or not.

The remarkable control that the structure has exerted in determining where the ore bodies were deposited is the outstanding feature of the geology of Aspen. Although most of the ore bodies along the two main productive faults have been found and exhausted, it is nevertheless probable that the future output will be

[13] Spurr, J. E., Econ. Geology, vol. 4, p. 305, 1909.
[14] Idem, p. 308.

derived chiefly from the Silver and Contact faults and from the minor parallel or "sympathetic" bedding faults in the zones adjoining those faults.

The ore worked in early days was rich in silver, owing to its content of native silver, pearceite ("arsenical polybasite"), argentiferous tennantite, and argentite. Barite is a characteristic associate of such ore. Bastin,[15] who visited the district in 1913, when some ore of this kind was still to be seen in place, concludes from his detailed study of the microstructure of the high-grade silver ore that the rich silver-bearing minerals are essentially of primary (hypogene) origin; that supergene enrichment has been most marked in those ores in which primary silver minerals were abundant; that the chief silver mineral of supergene origin was native silver, but in some places supergene pearceite and argentite were also deposited; and that the native silver disappears at depth and has clearly been deposited from descending water of surface origin. Spurr,[16] on the other hand, believes that the native silver has grown in place as the result of the oxidation of rich silver compounds and that there has been little downward migration and enrichment of silver. The fact, noted by both Spurr and Bastin, that the native silver is mainly associated with the rich primary silver-bearing minerals appears to favor Spurr's interpretation; but quantitative proof of either proposition is not at hand.

Native silver was found by Bastin to occur to a vertical depth of 1,200 feet. In the southern part of the district it persists to an even greater depth—1,500 feet; it is in tight ground in which the ore shows no other sign of alteration. Small bodies of such ore were found in the Hope tunnel, consisting chiefly of galena in barite with polybasite and a little chalcopyrite; the native silver is in prongs and wires, which are striated and grooved and thus appear as if they had been extruded from the polybasite upon which they are implanted.

Ore, to pay for shipment and smelter charges, must carry from 15 to 20 "points" (ounces of silver per ton plus units of lead), or, roughly, $15 to $20 a ton in silver and lead. Most of the ore mined in the last decade, however, has not been shipping ore but has been milling ore that carried a moderate percentage of lead in the form of galena and a few ounces of silver to the ton.

The chief producer has been the Molly Gibson mine. The ore from the deeper levels of this mine, according to Mr. Charles E. Anderson, manager, averaged from 2 to 3 per cent of lead and

[15] Bastin, E. S., Observations on the rich silver ores of Aspen, Colo.: U. S. Geol. Survey Bull. 750, pp. 41–62, 1924.

[16] Spurr, J. E., Econ. Geology, vol. 4, p. 316, 1909.

3 ounces of silver to the ton; it contained but little zinc, which did not increase in amount in depth.

The deepest workings in the Aspen district—those in the Molly Gibson mine—reached a vertical depth of 1,450 feet below the collar of the Molly Gibson shaft, or 2,880 feet below the outcrop. The Molly Gibson mine is regarded as exhausted, and it was closed down in July, 1923.

An enterprise of comparatively recent date is that of the Park Mining & Milling Co., which in 1921 completed a tunnel 3,165 feet long driven from the head of Keno Gulch to tap the large bodies of oxidized ore under Tourtelotte Park. Extensive bodies of highly limonitic ore were found, but previous operators had already removed through numerous devious workings the more valuable portions. On account of the low prices of silver and lead it did not pay the company to extract the remaining low-grade material, and in 1923 operations were at a standstill.

The Cowenhoven tunnel, which penetrates Smuggler Mountain somewhat north of the Molly Gibson mine for a distance of 2¾ miles, was being reopened by the Silver Mines Co. of America in 1923. It had been made accessible to a distance of 5,000 feet from the portal, and some prospecting was undertaken to find bodies of ore in or adjacent to the old workings. It was reported that the main purpose, however, was to explore some unprospected ground at 10,000 feet from the portal.

OXIDATION OF THE ORES AS RELATED TO THE GLACIAL HISTORY

There were plainly two epochs of alpine glaciation at Aspen. The earlier of these gave rise to ice streams that were by far the larger. An immense amount of erosion was done by the ice streams in drastically remodeling a region already deeply trenched by stream canyons, yet, remarkably enough, oxidized ores are common in the district, and the effects of oxidizing solutions have extended to great depths. It is purposed to discuss briefly the problem that is thus presented.

The moraines of the earlier epoch appear at altitudes above 9,000 feet, for below this they are covered by the younger moraines, and they extend up as high as 10,800 feet. The long summit of Richmond Hill is free from any evidence of glaciation, negativing Spurr's idea that a continuous ice sheet once covered the whole region. The older moraines consist of granite and quartzite boulders, but the granite boulders have crumbled to a coarse sand, so that only quartzite débris appears at the surface over large areas, and the normal forms of the moraines have been considerably subdued. The weathered state of the older moraines is excellently shown in the large pit formed by the caving of the Boulder shaft, on Smuggler Mountain. The granite boulders are oxidized and stained by limonite through and through, and in the sides of the pit the boulders do not project in relief, as they do in cuts in the younger moraines. As the sides of the pit slumped the crumbly granite boulders broke as readily as the finer material in which they are embedded.

In contrast to this thoroughly weathered condition the granite boulders of the younger glaciation, consisting of the granite of the same kind as that in the older moraines, are firm, coherent, and brilliantly fresh. Manifestly, a long time separated the two epochs of ice action. Other evidence of a considerable interglacial interval is afforded by the gullies that are deeply cut in bedrock above the younger lateral moraines on the northwest extension of Red Mountain but hardly notch these moraines where they cross them. This anomalous condition that the headward portions of the gullies are cut deeper in bedrock than the lower portions are cut in loose morainal material indicates that the headward portions were eroded during interglacial time. Presumably they could not have been formed before the earlier glaciation, because the ice of that epoch extended far above their upper limits, and therefore glacial erosion would undoubtedly have obliterated them. The lower stretches of these bedrock gullies were buried by the morainal detritus of the subsequent glaciation. Postglacial erosion has been too feeble to exhume the buried portions and has succeeded only in faintly notching the top of the lateral moraine. On the basis of the comparative amounts of erosion done, the interglacial interval must have been many times as long as the time that has elapsed since the retreat of the last glacier.

The ice streams obviously accomplished a large amount of erosion at Aspen. This is indicated by the great breadth and depth of the U-shaped troughs of Roaring Fork and its tributaries. A minimum measure of the amount of the deepening of the Roaring Fork Valley by ice action appears to be afforded by the hanging condition of the Hunter Creek valley, just northeast of the town of Aspen. This fine glacial trough stands 500 feet above the floor of Roaring Fork. Accordingly at least 500 feet of glacial downcutting was accomplished at the site of Aspen.

When was this work done? The glacier of the last epoch was not over 1,000 feet thick at Aspen and probably terminated a short distance below the site of the town, as shown by the large moraine partly spanning the valley just below the confluence of Maroon Creek. Near their ends glaciers as a rule have weak erosive power. The earlier glacier was nearly three times as thick at Aspen as the later one. Consequently most of the downcutting, as measured by the hanging valley of Hunter Creek, was probably done during the earlier glaciation.

Notwithstanding the great stream and glacial erosion so plainly indicated in the Aspen district, oxidized ores are common, and the effects of descending waters of surface origin are perceptible at considerable depths. Bastin has recently discussed the depth of oxidation at Aspen, and has shown that notable oxidation occurs in or adjacent to the ore bodies to a depth of 1,000 feet, though in distribution this oxidation is markedly spotty.[17] Analysis of the data presented by Bastin shows that all the deep oxidation he observed was above the level of Roaring Fork, the master stream of the district. Similarly, the wire silver seen by the writer at a vertical depth of 1,500 feet in the Hope tunnel is above the level of Castle Creek. According to Spurr, wire silver is abundant to considerable depths below water level, occurring at least as deep as 900 to 1,000 feet below the surface, even in places where the water level originally stood only a few hundred feet down.[18] But whether any notable quantity of oxidized ore or wire silver occurs below the level of the master streams of the district is not recorded.

The Aspen district is an area of abrupt, high relief, underlain by carbonate formations, and consequently it has a vigorous circulation of underground waters, especially along solution channels. Doubtless this combination of great relief and active movement of surface waters charged with oxygen along solution channels has produced the great depth of oxidation recorded by Bastin.

In the highest mines in the district, in Tourtelotte Park, all the ore is oxidized, as was noted by Spurr. For example, the ore bodies recently cut by the Park tunnel 600 feet below the outcrop are completely oxidized to porous, highly limonitic material, although in places they are 40 feet thick. This extensive oxidation is not wholly of postglacial origin but dates back at least to interglacial time. Tourtelotte Park lies above the upper limit of the last main glaciation, so the outcrops were not planed off by the ice erosion of that epoch. As Tourtelotte Park is the floor of a wide, shallow cirque high above Roaring Fork, it was not deeply eroded during the earlier, more mighty glaciation, as its shallowness proves. Therefore the oxidized ores of the park may date back to preglacial time.

The amount of glacial erosion in the Aspen district and the depth to which oxidized ores extend form but one side of a larger problem. That problem is the rate of oxidation as contrasted with the rate of erosion. One of the dominant impressions that the Aspen district makes, with its great canyons 3,000 and 4,000 feet deep intrenched

[17] Bastin, E. S., Observations on the rich silver ores of Aspen, Colo.: U. S. Geol. Survey Bull. 750, pp. 56–57, 1924.

[18] Spurr, J. E., Ore deposition at Aspen, Colo.: Econ. Geology, vol. 4, p. 315, 1909.

below an older surface of erosion, is the enormous amount of degradation that has been effected in geologically recent time. Nevertheless, the rate of oxidation of the ores has more than kept pace with the rapid rate of degradation. Possibly the reason is, as already hinted, that the great relief produced by the profound canyon cutting has so strongly stimulated the downward movement of oxygen-charged waters as to accelerate oxidation of the ores far beyond the rate of areal denudation.

ORE DEPOSITS IN THE SOUTHERN PART OF THE DISTRICT

MODE OF OCCURRENCE

The ore in the southern part of the district, on the west flank of Richmond Hill, just south of the area mapped by Spurr, occurs under different conditions from those in the near vicinity of Aspen. Extensive prospecting, both near the surface and at great depth, has disclosed no ore along the Silver and Contact faults in this area, in spite of the fact that the bulk of the ore near Aspen was obtained along these faults. It must be accepted as demonstrated that in this part of the district these faults are not favorable places for ore. This conclusion was already apparent to Spurr,[19] and it has been amply corroborated by the large amount of exploratory work subsequently undertaken. Spurr thought that some ore might be found along the Castle Creek fault, but this possibility still remains unrealized.

Ore occurs, however, in association with a steeply dipping sill of albite alaskite porphyry, which is peculiarly distinguished by its unfailing content of stout prisms of muscovite. This sill, because of its strong local importance, may be called the Little Annie sill, from the name of the mine that has yielded practically the only output on Richmond Hill.

The Little Annie mine, at an altitude of 10,540 feet on the west slope of Richmond Hill, is popularly credited with having produced $1,000,000 from silver-lead ore. To cut at considerable depth the ore body from which this ore was taken is the goal set for two long adits that are now being driven—the Hope tunnel and the Midnight tunnel, described on pages 24–28. The southward extension of this sill is being prospected at the Jewell shaft, at the Orinogo tunnel, in Lime Gulch, and at the tunnels of the Hurricane Mining & Milling Co., south of Lime Gulch.

The ore at the Little Annie mine occurs in a zone of shattered Weber(?) formation forming the hanging wall of the Little Annie sill of alaskite porphyry. As it has been assumed by the operators that the porphyry contact was the main factor in determining the

[19] Op. cit. (Mon. 31), p. 168.

position of the ore bodies, the sill has been the incentive of much exploratory work.

The sill trends north and dips steeply west; 1,000 feet north of the Little Annie shaft it is displaced along Winnie Gulch by a transverse fault, which is locally known as the Winnie fault, and 500 feet south of the shaft it is cut by another transverse fault, which may be called the Hope fault. This segment of the Little Annie sill lying between the Winnie fault on the north and the Hope fault is thus roughly 1,500 feet long. (See fig. 2.) In this all-important segment the sill is poorly exposed, but it does not exceed 100 feet in thickness. This narrow width is due to the fact that the sill here lies between two strike faults that diverge in depth. (See fig. 3.) The west boundary of the sill is the fault termed by Spurr the Annie fault. The east boundary is

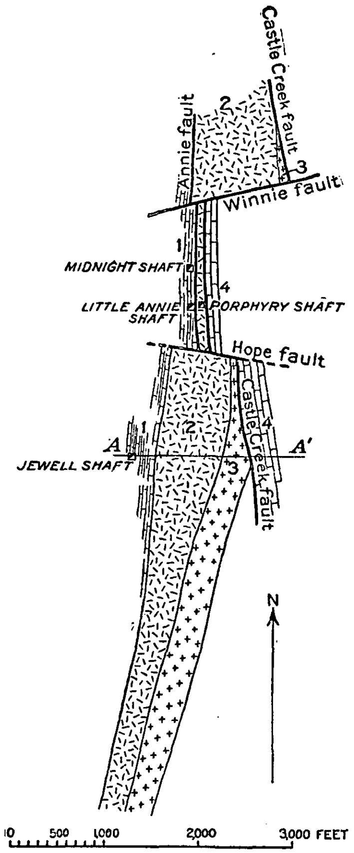

FIGURE 2.—Geologic map of area surrounding Little Annie mine, south of Aspen, Colo. 1, Weber (?) formation; 2, alaskite porphyry (Little Annie sill); 3, aplite; 4, Yule dolomite. *A–A'*, Line of section in Figure 5

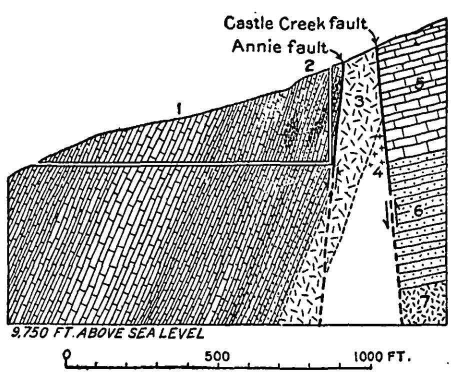

FIGURE 3.—Diagrammatic section through the Little Annie shaft, south of Aspen, Colo. 1, Weber (?) formation; 2, ore zone; 3, alaskite porphyry; 4, aplite; 5, Yule dolomite; 6, Sawatch quartzite; 7, pre-Cambrian granite

in the main the Castle Creek fault, although east of the Little Annie shaft there is some sericitized aplite, which is the rock encountered in the so-called Porphyry shaft.[20]

[20] The cross section through the Little Annie mine given on Plate 43 of the Aspen monograph is erroneous to the extent that it does not distinguish the highly porphyritic alaskite porphyry from the nonporphyritic aplite.

The segment of the Little Annie sill south of the Hope fault dips 70° W.; the dip of the segment at the Little Annie mine is not accurately known but is probably 70° W.; and the segment north of the Winnie fault dips 55° W., as determined in the Midnight tunnel. Now, because the Annie fault, which at the surface forms the west boundary of the sill, dips westward more steeply than the sill, the fault must, north of the Hope fault, in depth pass through and under the sill, and the upper contact of the sill must become a normal igneous contact. This behavior of the Annie fault in depth has been shown on cross sections B–B to F–F on Plate 14 of the Aspen monograph; but the section F–F is of particular interest now, because the graphic prediction as to the downward extension of the Annie fault made in that section has been verified at a depth of 1,000 feet in the Midnight tunnel, driven 20 years after the publication of the monograph. As will be shown, the deposition of the ore was determined by the Annie fault, which evidently afforded a passageway for ascending ore-forming solutions, and not by the contact of alaskite porphyry against the Weber (?) formation. The failure to grasp this significant distinction has caused much perplexity to some of the operators. The objective of all prospecting, as already mentioned, has been the contact of the alaskite porphyry sill with the Weber (?) formation instead of the Annie fault.

The ore occurs as irregular shoots or pods without definite walls in a wide zone of disturbed Weber (?) formation 400 feet long, extending from the Little Annie shaft to the Midnight shaft. The normal strike of the Weber (?) beds is north and the dip 70° W., but the beds resting on the alaskite porphyry sill are shattered and broken through a thickness of 200 feet, with resulting wide variations in strike and dip, locally even striking east. The Weber (?) formation consists here of black thin-bedded limestone, cherty dolomite, and shale. The shattering and disturbance of these beds in contact with the Little Annie sill is evidently due to movement on the Annie fault. Where the Annie fault is not present the Weber (?) beds are undisturbed, the contact of the sill against them is a normal igneous junction, and no ore occurs. The ore consists of a breccia in which the angular fragments of the Weber (?) beds are cemented by galena, sphalerite, quartz, barite, and calcite. Generally an insufficient amount of the sulphides and gangue minerals has been deposited to fill completely the interspaces between the angular fragments of country rock, so that the ore has characteristically a porous, drusy, or vuggy appearance. To a minor extent the fragments of country rock in the breccia have been replaced by galena, sphalerite, quartz, and barite.

Some of the ore from the Midnight shaft is notable mineralogically, in that it contains galena graphically intergrown with a resinous sphalerite, the scale of intergrowth being sufficiently coarse to be easily apparent to the unaided eye. The galena, which predominates in the intergrowths, forms rather narrow individuals as much as 0.7 inch long.

NATURE OF THE ORE-DEPOSITING SOLUTIONS

Microscopic examination of the ore from the Midnight mine throws some unexpected light on the nature of the ore-forming solutions of this part of the Aspen district. Along with the minerals recognizable in the ore by the unaided eye—galena, sphalerite, pyrite (extremely rare), quartz, barite, and calcite—there occur minute prisms of tourmaline and a little sericite. The prisms of tourmaline are nearly colorless where embedded in quartz, but where they project from the quartz into the fragments of country rock inclosed in the ore they show the distinctive deep-brown pleochroism of tourmaline.

The aplite inclosing the baritic galena-polybasite veinlets recently found in the Hope tunnel (see p. 25) has obviously been profoundly altered by the ore-forming solutions. Under the microscope it is seen to have been largely replaced by coarse sericite, barite, quartz, and dolomite, all these minerals being essentially of contemporaneous origin.

From this association of minerals—sericite, barite, and dolomite with tourmaline—it follows that the ore-depositing solutions were at a fairly high temperature, between "high" temperature and "moderate." The ore deposits are accordingly in the transition range between hypothermal and mesothermal deposits, to use the terms recently proposed by Lindgren.[21]

The ore-forming solutions are probably related genetically to the granodiorite porphyry. The evidence for this conclusion is as follows: The granodiorite, as has been shown, appears to have been intruded after the epoch of folding and faulting and is consequently the youngest igneous rock in the district. The ore deposits also were formed after the epoch of folding and faulting, and as the ore-forming solutions had a fairly high temperature it is reasonable to link them in origin with the granodiorite porphyry. More definite or conclusive evidence as to the nature of this relation has not yet been obtained at Aspen.

Spurr interpreted the mineralization at Aspen as having occurred in three stages—(1) deposition of barite veins; (2) deposition of

[21] Lindgren, Waldemar, A suggestion for the terminology of certain mineral deposits: Econ. Geology, vol. 17, pp. 292–294, 1922.

sulphides, sulphantimonides, and sulpharsenides of silver or silver and copper; (3) deposition of galena poor in silver and sphalerite.[22] Bastin's careful study of the microstructure of the ores can not be said to confirm this interpretation, but it indicates that the barite and other minerals were deposited essentially contemporaneously.[23] The evidence from the southern part of the district, which affords the new item that the ore-forming solutions were hot enough to develop tourmaline, favors the interpretation that the several minerals of the ore bodies were deposited during one stage.

PRACTICAL CONCLUSIONS

The Annie fault, not the hanging-wall contact of the alaskite porphyry sill with the Weber (?) formation, was the feature that determined where the ore bodies were formed. Therefore the fault and not the contact should be prospected. It happens that at and near the surface the Annie fault, where it is ore bearing, is also the contact of the porphyry and the Weber (?) formation, and because of this obvious association of porphyry and ore, the erroneous conclusion has been drawn (and acted upon during the last 15 years) that ore is likely to occur anywhere along the hanging-wall contact of the porphyry sill and the overlying Weber (?) formation.

A question of practical interest is whether any ore will be found to occur along the Annie fault as the fault passes in depth wholly into the alaskite porphyry. In view of the fact that the ore elsewhere in the Aspen district has been developed mainly by the replacement of limestone, the probabilities are strongly adverse to the occurrence of ore wholly inclosed in porphyry. Where the fault has passed entirely through the porphyry into the underlying formations, however, especially into the limestone of the Leadville formation, the probability that ore bodies occur is greatly increased.

The only valuable ore body so far known is that of the Little Annie mine, and it occurs in the fault block bounded on the north by the Winnie fault and on the south by the Hope fault. It can not be too strongly emphasized that the deep-level exploratory work so far done has not yet entered this fault block. Therefore, future work should be so prosecuted as to enter this known ore-bearing block as soon as possible. The intersections of the cross faults—the Hope and Winnie faults—with the Annie fault are possibly the most favorable places to search for ore in the unprospected portions of the fault block.

[22] Spurr, J. E., Econ. Geology, vol. 4, pp. 313–314, 1909.

[23] Bastin, E. S., Observations on the rich silver ores of Aspen, Colo.: U. S. Geol. Survey Bull. 750, p. 49, 1924.

MINES

HOPE MINING, MILLING & LEASING CO.

Since 1911 the Hope Mining, Milling & Leasing Co. has been driving a tunnel to cut the Little Annie ore body at a depth of 1,800 feet. The portal of this tunnel, the Hope tunnel, is on Castle Creek 6 miles south of Aspen, at an altitude of approximately 8,700 feet. The ore body is on the west flank of Richmond Hill, at an altitude of 10,540 feet.[24] The distance from the portal to a point vertically below the Annie shaft is 6,600 feet as measured in a straight line; yet although more than 11,000 feet of work has been done, the face of the tunnel is still far from the ore body. Three men were employed at the time of visit.

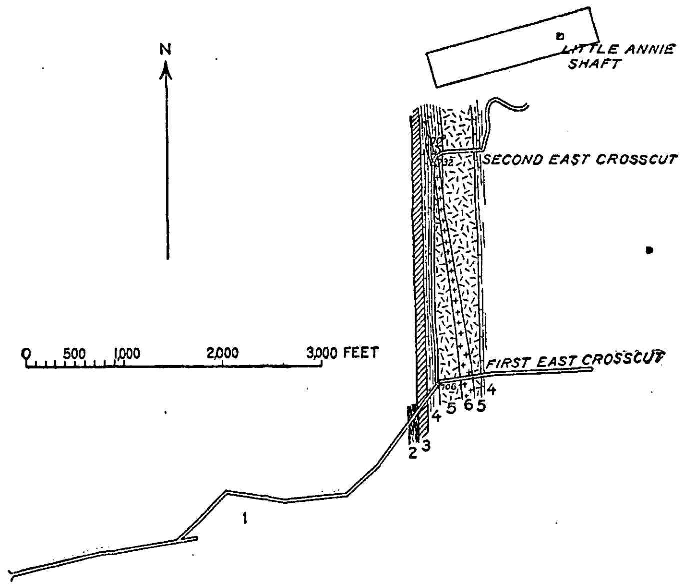

FIGURE 4.—Geologic map of the Hope tunnel, Aspen district, Colo. 1. Maroon formation; 2, black gouge; 3, gypsum; 4, black shales and limestones of Weber(?) formation; 5, alaskite porphyry; 6, aplite

The Hope tunnel traverses the sandstone of the Maroon formation for several thousand feet, then cuts through nearly 100 feet of black gouge containing angular fragments of gypsum and slabs of laminated sandstone, 165 feet of gypsum (true thickness, 100 feet), and 170 feet of the black limestones of the Weber(?) formation (fig. 4). At this point (station 706) the alaskite porphyry of the Little Annie sill was intersected and the First East crosscut was driven. The alaskite porphyry sill, as the term sill implies, has been injected parallel to the bedding and dips 80° W. here; its hanging-wall contact is a normal igneous contact, both the porphyry and the overlying

[24] Spurr, J. E., op. cit. (Mon. 31), pl. 43, *D*.

Weber(?) limestone being unshattered and there being no mineralization along the contact. In these respects conditions are entirely different from those at the Little Annie shaft, where the ore is in the shattered rocks that overlie the alaskite porphyry sill. The First East crosscut discloses the interesting fact that the alaskite porphyry is here split in two by an aplite dike 172 feet wide, with the result that 215 feet of porphyry lies west of the aplite and 65 feet of porphyry lies east of the aplite. The portion of the crosscut beyond the footwall of the alaskite porphyry was inaccessible at the time of visit but is said to extend back nearly to the pre-Cambrian granite. Great volumes of water under heavy pressure issue roaring from channel ways in the limestone and testify impressively to the active downward circulation of water in this region of high relief.

The main tunnel follows north along the hanging wall of the alaskite porphyry for more than 1,500 feet; but at 175 feet south of station 732 the aplite appears, having pierced diagonally through the porphyry and penetrated the overlying Weber(?) formation. The aplite is here only about 40 feet thick, and it thins considerably more in the next 300 feet along its course.

The thin wedge end of the aplite is shattered and mineralized and some pockets of high-grade silver ore have been found along its footwall. At the Turley raise the aplite is 25 feet wide, the hanging wall is a heavy black gouge, and the aplite throughout its width is sparsely interlaced with galena-bearing barite veinlets. Workings extend 80 feet above the main-tunnel level, and the footwall of the aplite is excellently shown, dipping 65° W. The underlying Weber(?) beds are thin, and many of them consist of black chert. The ore found along the footwall of the aplite consisted chiefly of galena in barite, with some calcite and polybasite and a very little chalcopyrite. Wire silver was common in some of the ore. The depth of this occurrence is 1,500 feet vertically below the surface; it is, however, above the level of Castle Creek. The silver appears to have been derived from the polybasite on which it occurs, and not to have been deposited as an enrichment product by water that descended from the surface.

In 1920 several carloads of ore high in silver were shipped.[25] The finding of this high-grade ore aroused strong hopes, but its spottiness has proved disappointing. Moreover, it led at first to the belief that the downward extension of the Little Annie ore body had been cut. This ore, however, is in a totally different geologic environment. The Hope tunnel has not yet been driven far enough north to cut through the Hope fault and into the fault block that contains the ore at the surface.

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[25] U. S. Geol. Survey Mineral Resources, 1921, pt. 1, p. 502, 1923.

The Second East crosscut, extending east from station 732, shows that the alaskite porphyry sill is here not split in two by aplite but is solid and 360 feet wide. Both contacts are normal undisturbed, unshattered igneous contacts and dip 70° W. The geologic features of part of the inner workings of the Hope tunnel are shown in Figure 5, which is drawn through the line *A A′* on Figure 2.

This cross section shows the geologic relations in the fault block that lies south of the Hope fault. The position of the Annie fault in this block is unknown. It will be seen that the hanging-wall contact of the Little Annie sill of alaskite porphyry, which is excellently exposed in both the Jewell and the Hope workings, is a normal igneous contact and that consequently no ore occurs along it.

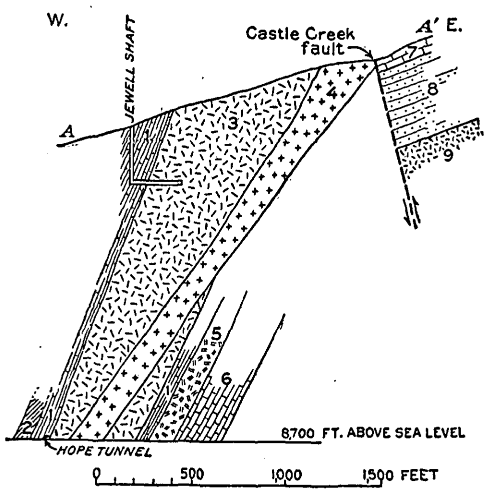

FIGURE 5.—Section through the Jewell shaft and Hope tunnel, Aspen district, Colo. 1 Weber(?) formation; 2, gypsum in Weber(?) formation; 3, alaskite porphyry; 4, aplite; 5, diorite porphyry; 6, Leadville limestone; 7, Yule dolomite; 8, Sawatch quartzite; 9, pre-Cambrian granite

MIDNIGHT MINING CO.

The Midnight shaft is 400 feet north of the Little Annie shaft. Originally it was sunk to a vertical depth of 500 feet, but the present workings are connected with the Little Annie tunnel, a branch from which intersects the shaft at a depth of 300 feet. At the time of visit it was planned to unwater the shaft. The main operations were on the Little Annie tunnel level and on a sublevel 50 feet below.

The largest piece of development work undertaken by the company is the Midnight tunnel, begun in 1914. The portal of this tunnel is in Queens Gulch, at an altitude of 9,700 feet. The tunnel is now more than 5,000 feet long, although in a straight line toward its objective, the Midnight shaft, it has progressed but 4,200 feet, and there still remains 2,200 feet to be driven; the vertical depth that will be attained when the shaft is reached is reported to be 878 feet. The tunnel traverses the country shown in the detailed geologic cross sections of the Aspen monograph (sections E–E and F–F of sheet XIV) and reveals the fact that the structural conditions are even more complicated than shown in those sections. The Weber(?) formation, which is shown in the sections as undisturbed, is in reality broken by numerous faults. At 2,800 feet from the portal the Little

Annie sill of alaskite porphyry was cut. (See fig. 6.) The contact is a normal igneous contact, dipping 55° W., like the bedding of the Weber(?) shale above it. To the operators it was somewhat of a surprise that no ore, or even signs of ore, were found on this contact, for it was thought that the conditions were the same as those in which ore occurs at the surface. The fact is, however, that the ore at the surface (at the Little Annie and Midnight shafts) occurred along a fault—the Annie fault—and that this fault, which was the controlling factor in determining the deposition of the ore, passes at depth through the alaskite porphyry sill. Farther in the porphyry was again cut, but here its contact with the Weber(?) formation is a vertical fault along which the rocks have been greatly shattered. This contact also is unmineralized. On account of the highly faulted condition of the rocks near the face of the tunnel heavy ground was encountered, which greatly impeded progress. The Annie fault is east of the tunnel; it is nearest to the tunnel at survey mark 130, where it is about 300 feet east. It does not appear to be worth prospecting here, except as a long chance.

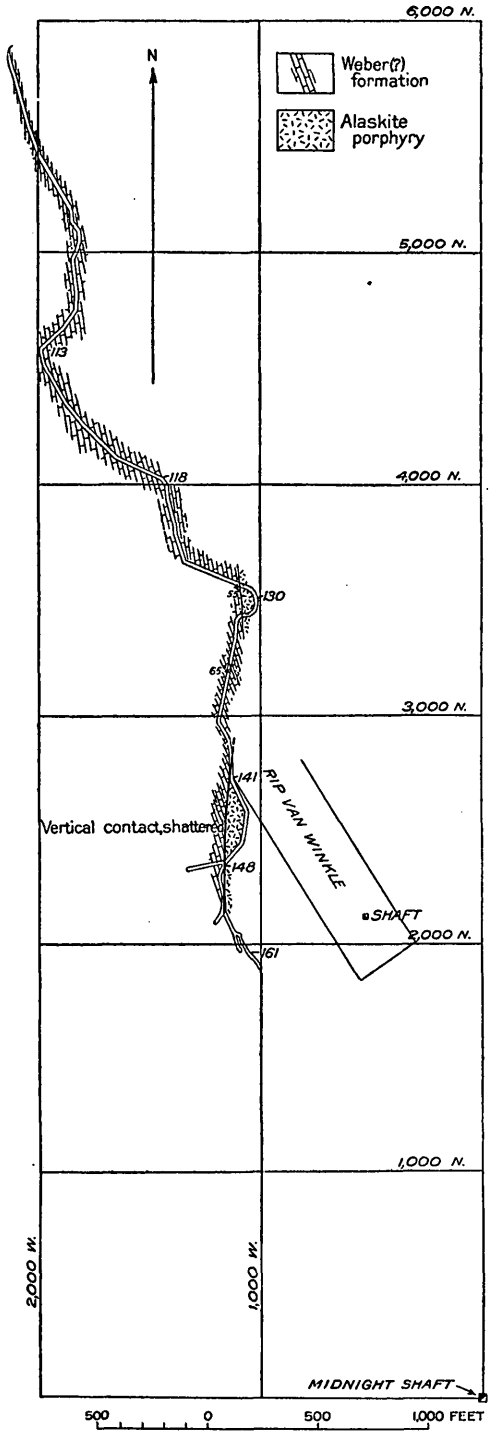

FIGURE 6.—Geologic sketch map of the Midnight tunnel, Aspen district, Colo.

Work in the tunnel had been suspended at the time of visit, and on account of its length and crookedness its continuance would be unprofitable. Operations were concentrated on the 300-foot level at the Midnight shaft, ingress to the workings being had by permission of the Hope Mining, Milling & Leasing Co. through a branch from the Little Annie tunnel, whose portal is at an altitude of 10,250 feet.

The ore occurs in the northern extension of the ore zone of the Little Annie mine. It consists of a breccia of black chert and jasperoid fragments which are cemented by galena, sphalerite, quartz, and barite. In places the cement is insufficient in quantity to fill the interspaces between the angular fragments of chert and jasperoid, and the resultant ore is markedly vuggy. The ore is reported to carry 2 ounces of silver per ton to each per cent of lead.