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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D WALCOTT DIRECTOR

ECONOMIC RESOURCES
OF THE
NORTHERN BLACK HILLS

BY

J. D. IRVING

WITH CONTRIBUTIONS BY

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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., June 24, 1903.

Sir: I have the honor to transmit herewith the manuscript of a report on the "Economic Resources of the Northern Black Hills," by J. D. Irving, with chapters by Mr. S. F. Emmons and Dr. T. A. Jaggar, jr. I would respectfully recommend that it be published as a professional paper.

Very respectfully,

C. W. Hayes,
Geologist in Charge of Geology.

Hon. Charles D. Walcott,
Director United States Geological Survey.

ECONOMIC RESOURCES OF THE NORTHERN BLACK HILLS.

Part I.—GENERAL GEOLOGY.

By T. A JAGGAR, Jr.

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ILLUSTRATIONS IN PART I.

ECONOMIC RESOURCES OF THE NORTHERN BLACK HILLS.

PART I.—GENERAL GEOLOGY.

By Thomas Augustus Jaggar, Jr.

INTRODUCTION.

The mining district of the Black Hills, comprised within the Spearfish and Sturgis quadrangles, was surveyed geologically in the summers of 1898 and 1899 under the direction of Mr. S. F. Emmons. The following pages present a brief summary of the geologic features, more especially with reference to ore-bearing formations. These are confined to the Algonkian and Paleozoic strata and their associated eruptives.

BIBLIOGRAPHY.

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3. Geological report on the Black Hills, by N. H. Winchell Report on a reconnaissance of the Black Hills of Dakota made in the summer of 1874, by William Ludlow, captain of Engineers, U S. A., 1875, pp. 17, 37

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GENERAL STRUCTURE.

The Black Hills are well known to constitute the type of dome structure. They rise like an island in the midst of the Great Plains, with culminating peaks of pre-Cambrian granite intrusive in Algonkian schists, and these same schists and granite may be followed outward from the center of the Hills to an encircling escarpment of Paleozoic rocks dipping away on the northern, southern, and eastern sides, and mantling over the schists to form an extensive forested limestone plateau on the west. The center of activity of the younger porphyry intrusions and of ore deposition is Terry Peak, a summit rising 7,069 feet above the sea, in the northern portion of the schist area exposed on the eastern side of the uplift. Northwest, north, and northeast of Terry Peak occur a large number of intrusive bodies in beds ranging from Algonkian to Benton Cretaceous. The structure and forms of these igneous bodies vary chiefly with the horizon of intrusion.

TOPOGRAPHY AND DRAINAGE.

The drainage of the northern Hills follows in general radial courses consequent upon the original slopes of the uplift as a whole. Where erosion has gone deepest this drainage has become modified by the development of valleys along the softer rocks, and, in consequence, subsequent valleys having courses concentric to the dome tend to follow along the strike of the Paleozoic and Mesozoic beds. The most conspicuous of these valleys is the well-known Red Valley, which forms a continuous depression around the Black Hills uplift.

Four streams drain the Terry Peak eruptive center, flowing east, northeast, and north; these are Elk, Bear Butte, Whitewood, and Spearfish creeks. The drainage system of each of these has eroded away strata which capped igneous intrusives; and the porphyries, by reason of their more resistant quality, usually form prominent eminences above the general level.

The westernmost of the streams mentioned, Spearfish Creek, forms for 20 miles an impressive canyon in the limestone plateau, from which the stream emerges into the Red Valley at Spearfish. For a portion of its course this stream, which is to-day one of the most powerful in the Hills, flows along the contact of the Algonkian schists with the basal beds of the Cambrian; above the mouth of Annie Creek the stream leaves the last outcrop of schist, and from here to the mouth of Robison Gulch, under Spearfish Peak, flows on Cambrian beds, cutting into porphyry masses at Annie, Squaw, and Rubicon gulches; then, entering the zone of north-dipping Paleozoics, progressively cuts its way across Ordovician, Carboniferous, and Permian beds before emerging on the Triassic lowland of the Red Valley (See Pl I)

Whitewood and Bear Butte creeks which flow to the northeast, traverse a more varied topography before they emerge from the Hills They take their rise among Cambrian strata and porphyries, and their headwater branches have assisted in carving out the northern portion of the exposed Algonkian core of the Black Hills uplift Through portions of their courses deep V-shaped gulches have been cut in the schists, and wall canyons in the Carboniferous limestone Each formation in turn has its characteristic erosion form, which varies little throughout the northern Hills, and is usually directly dependent upon its relative capacity for resisting erosion Indeed, the drainage as a whole, while retaining consequent courses in general for the master streams, shows many modifications by adjustment, more especially in the tributary branches, and occasionlly striking instances of capture are evident

Elk Creek, flowing east, drains on the south the high Algonkian plateau land which marks a portion of the area of maximum uplift The upper portions of its course are characterized by broad meadow bottoms and gentle slopes from upland "flats" consisting of Cambrian or porphyry caps over schist. Where the stream enters the limestone, which is here of extraordinary thickness, a magnificent canyon with vertical walls rising sheer from 200 to 400 feet has been cut Through this canyon the engineers of the Black Hills and Fort Pierre Railroad have built one of the most picturesque routes of travel in the country Steaming through this impressive gorge the traveler moving eastward finds it difficult for some time to discover any considerable dip in the massive limestones, which retain for several miles the appearance of uniform thickness in the precipitous cliffs that wall in the torrent Eventually, however, the canyon widens out and the limestone cliffs are replaced by bright-colored beds of the Minnelusa "alternate series," and then suddenly the characteristic gateway of Minnekahta limestone is passed and the train emerges into the broad lowland of the Red Valley with its red marls and tilled fields

TOPOGRAPHIC TYPES

The Algonkian schists form flat uplands, and when they occur as massive upturned quartzites frequently jut out in colossal walls Near Elk Creek one of these quartzite walls may be traced for miles, strongly resembling a dike Elsewhere the Algonkian forms the bottoms of streams that have cut through the softer Cambrian beds, or forms with its characteristic steeply inclined banding, the slopes of steep gulches, like Whitewood Creek along the line of the Burlington Railroad The many branches of the railway systems afford excellent sections of the Algonkian as they wind in and out along gullies and spurs to maintain their grade, and these railway branches and loops are now so numerous in the mining district as to form a conspicuous artificial feature in the topography; the same may be said of the innumerable tunnels and prospect holes with their dumps jutting out from the steep gulch slopes, the size of the dump an index of the depth of the digging. Thanks to this artificial "honeycomb" underground and the clean railway cuts above, much is now exposed to the geologist that was completely masked twenty years ago.

The Cambrian section, where exposed beneath a protecting cover of limestone, frequently forms wall cliffs of red and brown color, striped parallel to the stratification, one notable red band in the upper part of the formation being conspicuous in many places. The type locality occurs on the west side of Whitewood Creek, just below Deadwood. Where its protecting limestone cover has been eroded away the Cambrian is likely to weather into rounded forest-covered hills of inconspicuous outcrop, like those occurring south of Elk Creek in the vicinity of Meadow Creek. Immediately beneath the Ordovician limestone the Cambrian usually forms a bench, occasioned by the hard and salient "worm-eaten" (*Scolithus*) quartzite jutting out from beneath thick, soft, green shales (see fig. 1).

The Ordovician limestone, in consequence of this relation and of another shale band above it, is frequently masked by talus, but, where its thickness is sufficient, forms a yellow bench, well shown in Whitewood Canyon on the route of the Fremont, Elkhorn and Missouri Valley Railroad. This bench is rarely seen west of Deadwood, and the Ordivician is difficult to identify in Upper Spearfish Canyon. It occurs north of Annie Creek at several points in the canyon, at Crown Hill, and at Carbonate.

The Pahasapa formation, equivalent to the Madison limestone of the Rocky Mountains, is naturally the principal cliff-maker, and its escarpment forms a conspicuous feature in the landscape everywhere. A more irregular and variegated cliff, colored purple, red, and white, and presenting one of the most picturesque color effects, is made by the Minnelusa sandstone, forming the "sand hills" encountered in driving out from the Hills just before reaching the Red Valley. The sandy soil of the Minnelusa frequently produces holes and sand in the roads which traverse this zone.

The Minnekahta limestone of the Permian forms one of the most striking topographic features of the Hills. Dipping away with wonderful uniformity from the uplifted dome, the outflowing streams invariably cut through it a V-shaped gateway, making in the interstream spaces crescent-shaped scarps of the 30-foot limestone over the soft red sandstone that underlies it. The outer slope of the jointed limestone is usually washed bare and on the inner side of the Red Valley forms what has been aptly called a tessellated pavement The "Red Beds" themselves rarely present good exposures, though occasionally the streams which meander through the valley cut them into small buttes or mesas, capped by gypsum, which exhibit a bedded cross section. Such a section may be seen east of Whitewood.

Continuing outward from the Hills, the Jurassic beds outcrop on the inface of the Cretaceous escarpment that makes the outer wall of the Red Valley, and a conspicuous feature of these beds in the Sturgis district is a hard quartzite which forms angular blocks upon the slope. The crest of this slope is usually a rock face of coffee-colored or yellowish sandstone of Lower Cretaceous age. This sandstone slopes away toward irregular hills formed of other members of this series. The Dakota sandstone is the last hard, salient bed, and this in turn dips gently beneath a wide, arid tract of Benton black shale, the monotony of which is broken only by distant buttes of Niobrara limestone that appear upon the sky line far out across the plains.

STRATIGRAPHY.

DYNAMIC SIGNIFICANCE OF STRATIGRAPHY.

In the columnar section, fig. 1, are shown the average thickness and lithologic character of Paleozoic and Mesozoic rocks. In connection with the interpretation of dynamics of intrusion and accompanying mineralization, the distribution of thin-bedded and thick-bedded strata in the column is of great importance. Irving has shown the importance of shale beds as favorite horizons of intrusion; they are the readiest to yield to a viscous wedge of igneous matter. The columnar section shows three thick beds of soft material, one at the top of the Cambrian, the Permo-Triassic red beds, and the Benton shales. The first underlies the most massive "competent"[a] member of the whole series—i. e the great limestone, including both Ordovician and Carboniferous. The lower red bed underlies the massive layer known as Minnekahta or purple limestone, which is overlain by easily deformed thick beds of red marl, while the soft, black Benton shales underlie the Niobrara limestone

In addition to these three conspicuous shale horizons, other stratigraphic relations which would tend to influence intrusion are as follows: The Algonkian lamination abuts abruptly upward against the hard basal Cambrian quartzite or conglomerate, and this same lamination, while fairly uniform in its strike (NNW), varies in its inclination east and west of the vertical, though it is prevailingly westerly in the Terry Peak region. An example of change in dip of the schists occurs at Central.

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[a] Willis, Bailey, The mechanics of Appalachian structure, Thirteenth Ann Rept U S Geol Survey, pt 2, 1892, p 250 "A thrusting layer firm enough to transmit the effective force" in strata folding under lateral compression is called a "competent" stratum The same word may be applied to a stratum resistant to the upward progress of an intrusive magma, and thus competent to dome upward rather than split and mash like shale

in Deadwood Gulch, nearly opposite the De Smet open cut. (See section, p. 33.) Throughout the Cambrian, thin-bedded paper shales alternate with flags and sandstones, forming innumerable thin parting planes. Thin shales occur also above the Ordovician and in the Minnelusa, Jura, and Lower Cretaceous.

VARIATIONS IN THICKNESS.

The columnar section (fig. 1) shows average thickness for the northeastern part of the Black Hills. These figures are generalized from sections measured in Spearfish, Whitewood, Bear Butte, and Elk canyons. The progressive variation in this series of measurements, which is most significant in connection with the intrusives, is shown in the diagrammatic strike section (vertical exaggeration × 2.5) from northwest to southeast inserted on the map, Pl. I. From a thickness at Beaver Creek of probably not more than 400 feet, just west of the mapped area, the Siluro-Carboniferous massive limestone, grouped as a single competent member, thickens to more than 700 feet in Spearfish Canyon. The Cambrian beds maintain throughout this region a rather uniform thickness, but probably diminish where the limestone is thickest. There is some evidence that the present course of Spearfish Canyon marks the axial region of a gentle syncline of deposition under the great limestone. For this reason the thicknesses in the section have been referred to an upper datum level, namely, the top of the gray Pahasapa limestone.

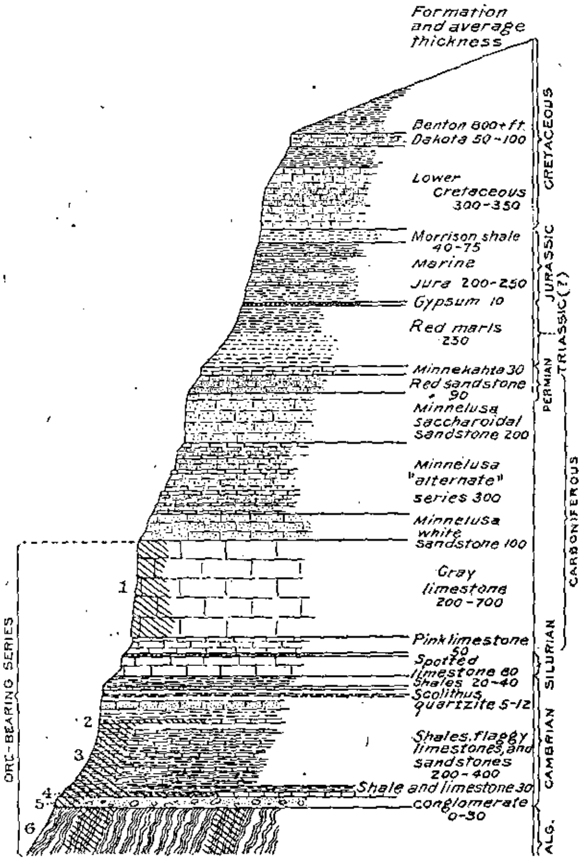

FIG. 1.—Generalized columnar section of northern Black Hills.

N. B.—The beds here designated Silurian have recently been determined to belong rather to the Ordovician.

The Algonkian surface thus sectioned is seen to be warped into undulations. That some such undulations occur, and of much more pronounced relief than that represented in the section, is amply proved at several points. One of these is between Englewood and Nevada Gulch, where there is a rise in the Algonkian-Cambrian contact of 400 feet in a northwest direction; that is, along a line tangent to the curvature of the elliptical area of the Black Hills uplift. Similarly the schist surface beneath the Cambrian at Brownville, on upper Elk Creek, shows a very rapid rise westward toward Woodville. Coarse Cambrian conglomerate fills hollows between ancient Algonkian quartzite reefs on the upland 4 miles southeast of Virginia, on Bear Butte Creek, so that irregular relief in the original Algonkian surface, as well as irregularities induced by deformation, may be safely postulated. Warping of the schist surface in post-Paleozoic time probably proceeded largely by small slippings on lamination planes. These movements, when communicated to the flat-lying Cambrian beds above, produced innumerable small fractures—the "verticals" of the mines. The coincidence in trend between verticals and Algonkian lamination planes (NNW.) is remarkable. The thickness of the Algonkian is unknown, but there is good reason for supposing that its nearly vertical structure marks a series of isoclinal folds in which eventually some recurrent horizons may be identifiable. As is to be expected in isoclinal structure, the schistosity usually conforms to the original bedding, but in places where the axial region of a fold is exposed the lamination is seen to be distinctly transverse to the bedding, as in Deadwood Gulch, near the town of Central. (See Pl. III.)

East from Spearfish Canyon the great limestone shows a remarkable thinning, from 700 feet to a total thickness of probably not more than 100 feet on the flanks of Polo Mountain, a distance of 6 miles. The Cambrian thickens, but not in the same proportion; at Deadwood it has a thickness of between 400 and 500 feet. From Polo Peak, where the limestone stratigraphically overlies the greater porphyry masses of the Terry Peak complex, this massive member steadily thickens southeastward, reaching 300 feet at Whitewood Canyon, about 500 feet in Bear Butte Canyon, and probably more than 800 feet in Elk Creek Canyon. The Cambrian beds thicken at Bear Butte Creek, and then thin away to between 100 and 200 feet south of Elk Creek; and farther south, on the flanks of the Harney Range, the Cambrian almost disappears.

Summarizing this section from Beaver Creek to Elk Creek, the thick limestone in Spearfish Canyon separates two areas of igneous irruption and Algonkian elevation, namely, the Bald Mountain and Nigger Hill mining districts. The Terry Peak center of irruption underlies the thinnest portion of the limestone. The Two Bit region of maximum development of sills is where the Cambrian is thickest, and the Runkel region of large porphyry masses in and above the limestone is where the Cambrian thins and the limestone becomes thickest. A study of the map will show these relations. The Nigger Hill Algonkian area lies outside of the mapped area, on the west. (See Pl. I.)

The paleontologic, lithologic, and topographic characters of the geologic column are best expressed in tabular form. Local formation names are avoided except where already in the literature of the Black Hills.

Geologic formations in northern Black Hills

Period	Epoch	Formation	Lithologic character	Topographic character	Fossils
Quaternary	....	....	Stream gravels, probably carrying placer gold in places.	Fills saddles and hollows, usually divides, scattered bowlders on the plains	
Tertiary	Eocene? ... (Oligocene)	White River	Clays, white, pink, or buff Small fragments of white rhyolite in conglomeratic layers	Similar to above, but less abundant Often under the Pleistocene gravels	Vertebrate remains, Mesohippus, Ischyromys typus
Cretaceous	....	Benton shale.......	Dark shales or clay........................	Plains................	Fish scales and teeth.
		Dakota sandstone ..	Brown sandstone with limonitic nodules...	Outer escarpments of Black Hills	Plant remains
		Lower Cretaceous ..	Sandstones, buff, white, and gray, limestones, colored clays, green shale, carbonaceous beds	Crest of outer wall of Red Valley and irregular hills and escarpments	Plants, cycads, etc
Jurassic	....	Morrison	Fresh-water deposits, green shales, sandstones and clays	An inconspicuous bed in outer wall of Red Valley	Saurian remains
		Marine Jura	Buff marl, sandstone, oyster limestones, green and red clays, marls, and shales	Lower beds in outer wall of Red Valley	Belemnites, Ostrea, Trapezium, Pseudomonotis, Tancredia, Cardioceras, Lingula brevirostris
Triassic	....	"Red Beds".......	Red marl with gypsum	Red Valley	
	Permian...	Minnekahta limestone	Uniform purplish banded limestone, weathers white, strong bituminous odor when crushed.	Tesselated pavement on inner slope of Red Valley, escarpment and "gateways" of streams.	Bakewellia, Yoldia? Edmondia?

Carboniferous		Lower red bed	Red sandstone, soft and marly	Inner slope of Minnekahta escarpment	
		Minnelusa	Alternate limestones and thicker sandstones, somewhat colored	Variegated striped cliffs and sandy hills	
		Pahasapa, equivalent to Madison of Rocky Mountains	Massive limestone, gray, pink, or buff, sometimes cherty. Sometimes silicified and ore bearing	Massive cliffs, the greater escarpment	Spirifer, Syringopora, Productus, Seminula, Zaphrentis, etc.
		Englewood limestone, Eocarboniferous, equivalent to Lowest Mississippian (Chouteau or Kinderhook)	Pink or purplish thin-bedded limestone with red non-stained fossil mollusks. Purple or green shales below.	Frequently concealed beneath talus. Shows an apparent unconformity of erosion between it and the gray limestone above, though dip is accordant	Fenestella, Orthothetes leptæna, Spirifer, Chonetes logani, Reticularia peculiaris, Syringothyris carteri, crinoids.
Ordovician		Whitewood limestone, equivalent to Upper Trenton	Peculiar spotted massive limestone, usually buff with brown or reddish spots, sandy. Very large fossils.	Bench usually masked by talus	Endoceras, Maclurea, Receptaculites, Halysites, Streptelasma, Lituites, Orthis, annelid trails, Buthotrephis, Murchisonia.
Cambrian		Deadwood Formation, equivalent to Middle Cambrian of the Rocky Mountains	Conglomerate, quartzite, ferruginous sandstones, many alternations of green shale, limestone breccias, fucoidal limestone flags, at the top Scolithus sandstone or quartzite, and thick green shales. Ores commonly near the base.	Walls of recent canyons or old graded slopes, usually a pronounced bench	Obolus, Hyolithes, Dicellomus, Asaphiscus, Olenoides, Ptychoparia, Acrotreta.
Algonkian			Mica, graphite, and hornblende schists, metamorphic quartzite and conglomerate, and some pre-Cambrian intrusives. Locally pyritiferous and carrying free gold	Flat-topped plateaus and headwater valley bottoms.	

INTRUSIVE PORPHYRIES

LITHOLOGY

The porphyries vary in kind from rhyolite, diorite-porphyry, and syenite-porphyry to more alkaline rocks, which may be classed as phonolites and grorudites. Irving[a] has described many of the types, and there is here a remarkable series of gradations which renders the region exceptionally favorable for study of magmatic differentiation. He has distinguished the following families:

Grorudite.—Highly alkaline rocks containing orthoclase, quartz, ægirine-augite, and ægirine. In some types accessory albite, microcline, and biotite. Localities: Terry Peak, Bald Mountain, Elk Mountain, Lost Camp Creek, Annie Creek, sheet on the Burlington Railroad east of Terry Peak, and in the Sunset mine.

Phonolite.—Rocks rich in soda, forming the more basic phase of the grorudites. Composed of orthoclase, anorthoclase, microcline, ægirine-augite, ægirine, nepheline, nosean with accessory hauyne, biotite, magnetite, titanite, melanite garnet, and possibly leucite. Localities: Ragged Top Mountain, Squaw and Annie creeks, Calamity Gulch, Mato Tepee, Green Mountain (peak next west of Bald Mountain), Whitetail Gulch, east slope of Bald Mountain, and False Bottom stock.

Rhyolite-porphyry and dacite.—Phenocrysts of orthoclase, plagioclase and quartz in a fine-grained groundmass of quartz and feldspar, hornblende and biotite in varying amounts. Localities: Head of Squaw Creek, Foley Peak, Texana, Custer Peak, Butcher Gulch, Deadman laccolith, north side of Vanocker laccolith, Two Bit, Pluma, Bear Butte, lower portions of Sheep Mountain, Whitewood Canyon laccolith, dikes in many portions of Terry Peak district, Crow Peak, Inyankara, Sundance Mountain, and Warren Peaks.

Andesite-porphyry, diorite-porphyry, and diorite.—Porphyritic rocks containing phenocrysts of plagioclase, orthoclase, hornblende and biotite in a fine-grained groundmass of plagioclase, quartz, and chlorite. The rock shows transitions to trachytic forms which may be called syenite-porphyry. Localities: Sills in Squaw Creek and in Ruby Basin, at the Needles, and in the region of the Vanocker laccolith.

Diorite forms the Deadwood Gulch stock above the town of Central. It is a gray rock of granitoid texture, showing a tendency, however, to automorphism in the component minerals; it contains hornblende, plagioclase, quartz, biotite, and accessory orthoclase.

Lamprophyre.—A basic rock in small dikes cutting the diorite-porphyry of the Needles, and again near the head of Iron Creek, it is composed of a fine automorphic aggregate of augite and feldspar, with accessory hornblende and magnetite. Irving considers it the final and basic representative of the soda-rich magma that constitutes the principal Black Hills eruptive series.

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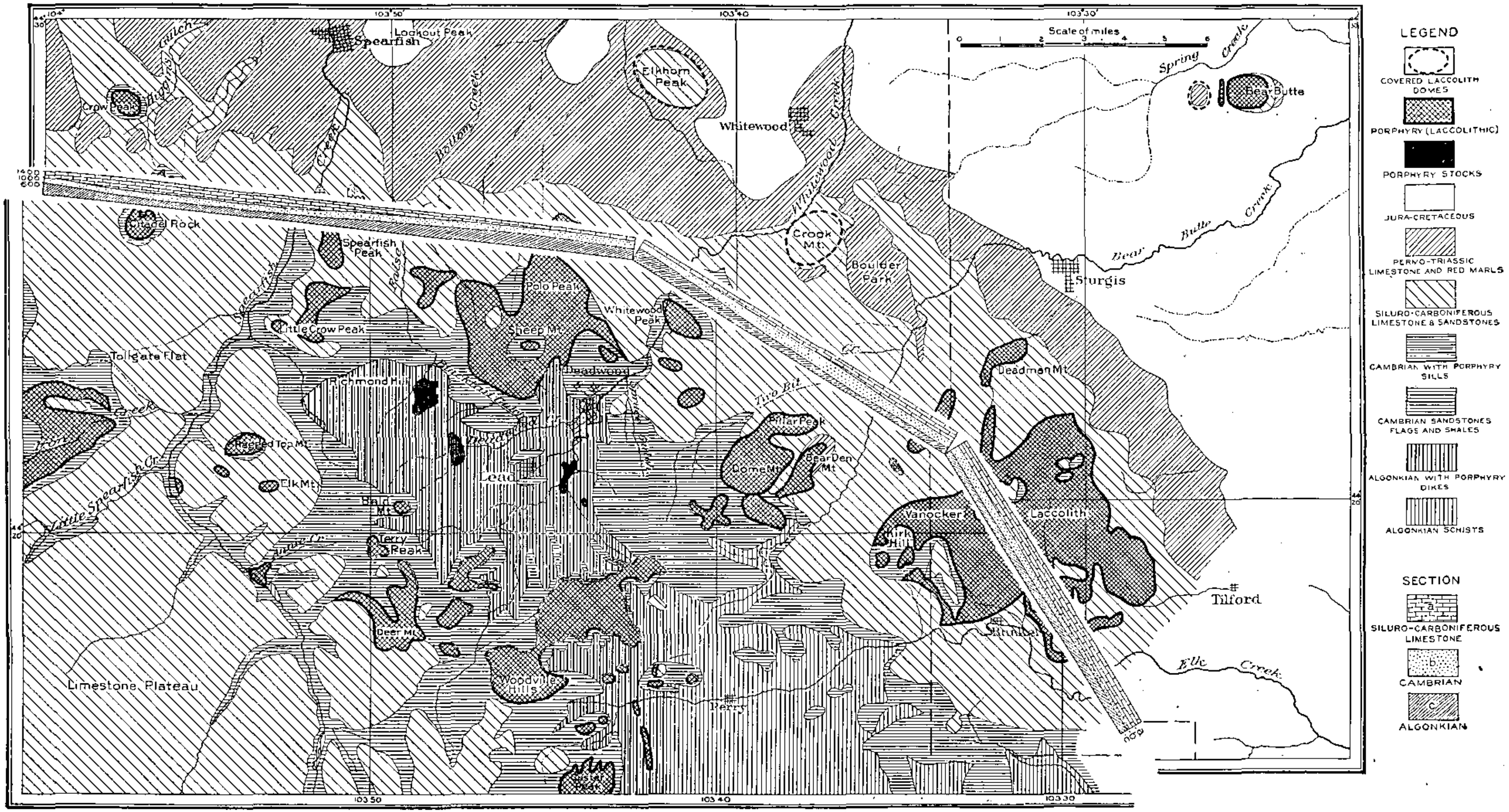
[a] Irving, J. D. Annals New York Acad. Sci., vol. 12, No. 9, p. 244 et seq.



GEOLOGIC MAP OF NORTHERN BLACK HILLS.

It will be seen from the above that the rocks represented are not unlike many others that have been described from laccolithic mountains of the Rocky Mountain region,[a] and it is not possible at present to state positively whether a sharp distinction, marking different eruption periods, may be drawn between the phonolite-grorudite and the rhyolite-andesite magmas. The evidence points rather to a gradual transition between the two. The terms rhyolite and phonolite are unfortunately associated with extrusion, and it might be less confusing to speak of these rocks as granite-porphyries and monzonite-porphyries, but their structure would hardly warrant such a terminology. In distribution the dike region of the schist area contains both phonolitic and rhyolitic rocks; the sills of Two Bit and Squaw Creek districts are in general andesite-porphyry and diorite-porphyry, the outlying thick "plug-like" laccoliths, as well as a great portion of the greater Terry and Bearlodge complexes are mostly rhyolite. But over the rhyolite on many hills, as Terry, Deer, Bald, and Sheep mountains, occur phonolitic caps, and the mass of Ragged Top, the Spearfish Peak group of laccoliths in the Carboniferous, and Mato Teepee are phonolite. The diorite magma is represented by a great stock in Deadwood Gulch, and its porphyry forms the mass of the Needles to the west and portions of the Vanocker laccolith to the east.

RELATIVE AGE OF PORPHYRIES

Differences in relative age among the porphyries certainly occur if the transection of one dike by another may be considered conclusive evidence that the second is younger than the first. This evidence, however, has no conclusive value in a single instance, for one portion of a magma might readily crystallize and split up to receive later injections of differentiated material originally part of the same igneous fluid. Between the solidifying of No. 1 and the injection of No. 2 the time elapsed may not have been great enough to cover the whole period of solidification of the larger masses of No. 1. If this were true a later injection of No. 1 might elsewhere cut an already solidified body of No. 2, in which case the apparent relations in age would be reversed. The preponderance of evidence would seem to show that in the Black Hills the phonolite magma as a whole is younger than the rhyolite magma.

Many occurrences in the field of dikes of one kind of porphyry cutting another may be cited. In the Two Bit district the greater masses of syenite-porphyry vary from a hornblende facies to one characterized chiefly by large orthoclase phenocrysts with poikilitic intergrowths of plagioclase and other minerals. Dikes which cut this rock are in general like the mass of Bear Den

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[a] See Cross, Whitman, The laccolithic mountain groups of Colorado, Utah and Arizona: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893. Also Weed and Pirsson, Judith Mountains of Montana: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898.

Mountain, which is an outlying subordinate laccolith. They are of trachytic, light-colored porphyry, showing pink microcline phenocrysts. They may bear some relation to the phonolites. A similar rock with amber-colored feldspar phenocrysts in a gray matrix cuts fine-grained white aphanitic rhyolite in a small dike on the Terry branch of the Fremont, Elkhorn and Missouri Valley Railroad, on the spur between Fantail and Nevada gulches. (Fig. 2.) Near Alkali Creek, on the divide from Vanocker Creek, numerous dikes cut the fine-grained rhyolite mass. These are a purplish trachytic rock, with glassy feldspar phenocrysts, showing striation (probably oligoclase) and a decomposed bisilicate. Other cases of the rock with phenocrystic pink (microcline) feldspar cutting the rocks of the rhyolite-andesite series occur on the spur south of White Rock, just above Deadwood, and on the ridge west of the head of Spruce Gulch. Near the sawmill north of Kirk Hill a gray rock containing much mica and yellow feldspar occurs as a dike cutting light-gray rhyolite which shows some hornblende. It is probable that these are mostly phonolitic rocks which cut rocks of the rhyolite-andesite magma. Irving has described four cases of phonolites cutting quartz-porphyries and diorite-porphyries.

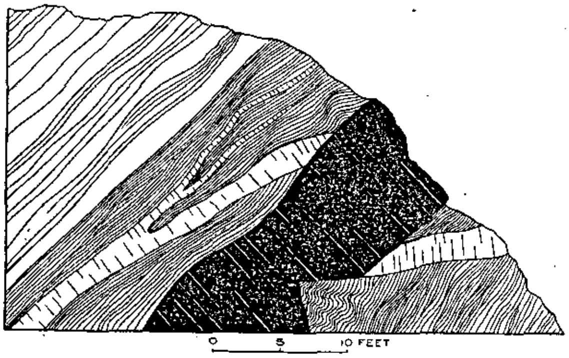

FIG. 2.—Green phonolite cutting rhyolite-porphyry, Fremont Railroad, near Nevada Gulch.

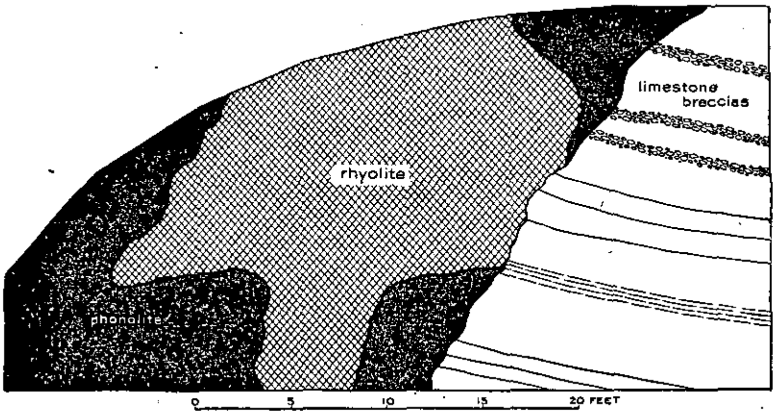

FIG. 3.—Rhyolite cutting green porphyry near Aztec.

A very unusual case (fig. 3) is shown in a section near Aztec, on the Burlington Railroad (Spearfish branch). Here a mass of green phonolitic phorphyry is apparently cut by an irregular swelling intrusion of white rhyolite of the fine-grained decomposed type so common in the region. Both occur, as shown, at a sloping dike contact with Cambrian shales. All the evidence in this case would show the rhyolite to be the younger, or contemporaneous with the phonolite. The second alternative is the more probable. The two magmas may grade into each other, and in this case perhaps the green ægirine rock was still viscous when the stream of white rhyolite was injected through it. It is hoped that more extended study of the petrography of the region will throw light on these relations.

GEOLOGICAL AGE OF PORPHYRIES.

The geological age of the porphyries may be stated in only the most general terms. The Bear Butte and Little Missouri Buttes laccoliths were intruded into Benton Cretaceous and were unquestionably covered by Niobrara limestones. Jenney has found pebbles of Black Hills porphyries in the conglomerate at the base of the White River beds to the southeast, and similar fragments occur in the Tertiary beds at Lead. The Lead Tertiary clays (Oligocene?) are deposited in an old topography 1,800 feet below the present porphyry summit of Terry Peak and on divides 300 feet above the adjacent gulches. As these clays were flood-plain or lake (?) deposits, of a mature stage in the early Tertiary dissection of the region, an additional 200 feet may be considered a most conservative estimate of height for the original porphyry upper limit of the Terry Peak Mountains. This porphyry at the time of its intrusion was covered by a thickness of strata not less than that of all the formations below the highest beds invaded; a minimum estimate would make this not less than 2,500 feet. This would imply a total thickness of rock eroded away above the present Tertiary beds at Lead of 4,500 feet (2,000 erosion + 2,500 thickness); accordingly, the later limital epoch of the intrusion period may be expressed as the beginning of a 4,500-foot erosion period prior to the Oligocene, while the earlier limital epoch is the Niobrara. Between these there is the choice of Pierre, Fox Hills, Laramie, and Eocene times for the intrusion.

By analogy with the Rocky Mountains the greater uplift in the Black Hills probably took place after the close of the Laramie. The only evidence in the immediate vicinity of the Black Hills bearing on the question whether Laramie beds ever extended over the present site of the hills is the fact that they are tilted up by the Black Hills uplift on the west side; if they did so extend they may have attained a thickness of several thousand feet. The thickness of the Jura-Cretaceous below the Laramie is 4,000 feet.[a] If the first uplift of importance was in Eocene time and Laramie beds were present, the erosion depth at Lead may be increased by several thousand feet. There are analogous intrusions of Eocene age in the Rocky Moun-

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[a] The writer is indebted to Mr. N. H. Darton for data and discussion on this question.

tain district in sufficient number to render very probable the occurrence of igneous activity, concomitant with uplift, in the Black Hills at that time. That orogenic disturbances took place concomitant with intrusion is proved by the relation of the Algonkian-Cambrian contact to the porphyries at many places, the latter filling fault fissures. After the energetic erosion that led to deposition of Oligocene beds and probably reduced the topography of the Hills to much lower relief than that of the present day, "there was a further uplift, which has given a very strong tilt to the White River deposits."[a] No porphyry now revealed can have accompanied this last uplift, which may still be in progress. By this last movement the Oligocene beds at Lead have been lifted and the present gulches have since been carved below them. The following is a summary of the evidence for the Eocene age of the eruptives:

Evidence from geology	Laccoliths in the Benton Deformation concomitant with intrusion. Porphyry pebbles in Oligocene sediments.
Evidence from analogy	Post-Laramie uplift of Rocky Mountains Post-Laramie intrusions of Rocky Mountains
Evidence from physiography	Probable erosion of 6,000 to 8,000 feet of strata from above level of present Tertiary clay at Lead

DISTRIBUTION OF IGNEOUS BODIES.

The intrusive rocks occur as stocks and dikes in the Algonkian schist, sills in the Cambrian shales where that formation is thick, and laccoliths, which thin out into sills in the Cambrian, but rise into thick domes of limited horizontal extension where the magma has broken through the massive Carboniferous limestone and escaped to higher horizons. These relations will be best understood by reference to the map (Pl. I), where Custer Peak, the Woodville Hills, Deer Mountain, Dome Mountain, and the Iron Creek mass represent laccoliths in the Cambrian associated with the broad sill district; this in turn surrounds the schist area of stocks and dikes. Outlying masses, of steep domical form, which have broken through the limestone are Ragged Top, Citadel Rock, Crow Peak, Whitewood Canyon laccolith, Pillar Peak, Bear Den Mountain, Deadman laccolith, Tilford laccolith, and Bear Butte. The great mass of the Vanocker laccolith on the east is an exceptionally large body which in part has broken across the limestone. To the north Crook Mountain and Elkhorn Peak are domes of Minnelusa sandstone, where erosion has not yet revealed the porphyry.

In the schist area many hundred dikes occur, trending usually about N. 30° W., parallel to the Algonkian lamination, and this trend in a general way corresponds with that of some of the larger laccolithic groups.

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[a] Quoted from Mr Darton letter to the writer

Thus a line of porphyries may be drawn from Custer Peak to Crow Peak, from the Tilford laccolith to Elkhorn Peak, and from Two Bit to Polo Peak, possibly indicating an alignment of conduits beneath. At four points stocks have been indicated on the map, namely, at False Bottom Creek, Deadwood Gulch, Pluma, and a small mass east of West Strawberry Gulch; there are probably others in the hills west of Lead. The mass at Pluma is a great dike for a portion of its course, but becomes complicated with stock-like bodies, and is of such size as to warrant independent mapping. The area of sills in Cambrian shales has its best exposures on Two Bit Creek, Spruce Gulch, on the ridge southeast of Deadwood, on False Bottom Creek at Garden, along Squaw Creek, and on Annie Creek.

HOMESTAKE DIKES.

A section from southwest to northeast through the Homestake and Caledonia open cuts (fig. 4) serves to illustrate the frequency and thickness of dikes in the schist area that were conduits for westward-spreading sills and laccoliths. Here the schist dips to the east and contains much quartz, which in places is distinctly quartzite, elsewhere is massive quartz. The schist is red and ferruginous in this region, but talcose, slaty, or graphitic where less altered. The dikes average 35 to 40 feet in thickness. Three dikes in the Homestake section are associated with breccias: in one case on the foot wall; in another the fragments of schist are embedded in the igneous rock; and in the third case a breccia 6 inches thick occurs on the hanging wall of a small 4-foot dike high up on the eastern slope of the main cut. These breccias sometimes contain fragments of both schist and porphyry, and therefore might be the product of faulting subsequent to intrusion. In other cases they are unquestionably the product of brecciation concomitant with intrusion.

PSEUDO-CONGLOMERATES.

Besides the dip away from the core of the Black Hills, which, on the rim of the uplift, uniformly indicates deformation of once horizontal sediments by forces other than those immediately generated by the recent intrusives, there is interesting evidence presented by the limestone breccias which are so abundant in the Cam-

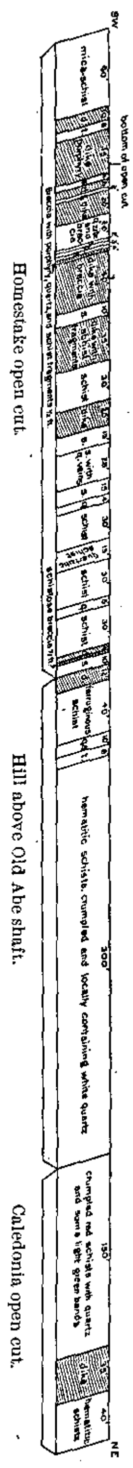

Fig. 4.—Section through *Homestake* surface workings. *s*, schist; *d*, dike; *t*, talus; *q*, quartz. Dip, 75° NE.; strike, N. 30° W. (both approximate). The sections probably overlap, making the error on the side of excess. Dikes do not always coincide with the lamination as shown, nor is the dip and strike uniform.

brian. These occur in lenticular masses, sometimes merging into unbroken limestone flags interspersed among beds of green shale, the flags carrying trilobite fragments. These fragments of trilobites may also be seen in the flat or rounded "pebbles" of the limestone breccias, and this bars the possibility, suggested by Crosby,[a] that these breccias are conglomerates derived from an Algonkian limestone. The breccias in question were formed by crushing, accompanied in some cases by minute foldings of the limestone bands, the brittle laminæ breaking on the most acute flexures, or else breaking into flat pieces under the influence of pressure without any considerable flexure.

Infiltration of waters which dissolved off the edges and corners of these broken fragments later cemented the mass by depositing crystalline dolomite as a matrix for the pseudo-conglomerate. These "intraformational breccias" are abundant in the Two Bit district, where are also many sills and dikes of porphyry, and the question frequently arises in the field whether the deformation which fractured the limestone beds, and the waters which cemented them, were in any way associated with the intrusives. A negative answer to this question was clearly afforded by the upper contact of the sill figured (fig. 5). In the lenticular masses of limestone breccia here shown there are developed locally distinct folds, which pass by gradations into a breccia, holding fragments tilted at all angles, frequently without order or arrangement. Careful examination shows that often these may be resolved into former folds by joining the adjacent "pebbles." The work of solution and recrystallization on the fractured beds has nearly obliterated the original crumpling.

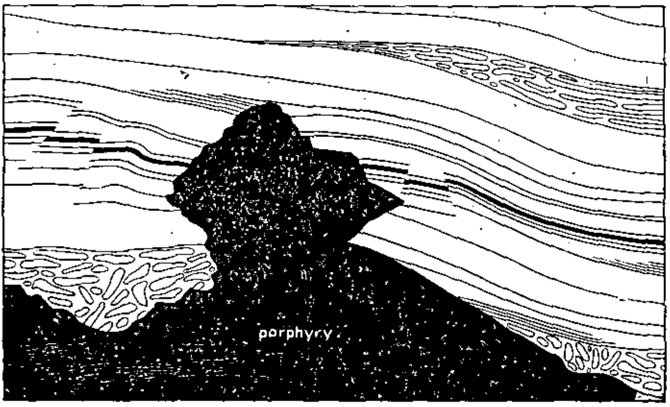

FIG. 5.—Upper contact of sill cutting limestone breccias, Galena.

This locality, showing distinct crumpling occasioned by the porphyry in some of the beds and the ancient crumpling associated with the development of the pseudo-conglomerates, offers an excellent opportunity to test the question whether the porphyry was immediately the occasion of the brecciation. The contact shows

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[a] Proc. Boston Soc. Nat. Hist., vol. 23, p. 497.

distinctly that it was not. The limestone breccias are irregularly cut across by the porphyry both on the old folds and in places where all trace of folding has disappeared. In other cases where fragments of the breccia still remain horizontal the porphyry cuts across fragments and matrix alike. The unbrecciated limestone bands are occasionally folded and fractured by the porphyry, and on the fractures there is evidence of some recrystallization, so that it is not impossible that in places a newer breccia may owe its origin to deformation by intrusion; but in most cases the limestone breccias of the Cambrian were formed before the intrusives. This is further evidenced by the fact that these breccias occur in many parts of the Hills where the younger eruptives are absent, so that it is fair to conclude that the evidence indicates a period of deformation later than the Cambrian and earlier than the laccolithic intrusives. Similar limestone breccias occur less abundantly in the Carboniferous and Permian limestones. Weed has figured[a] a Cambrian limestone conglomerate from the Judith Mountains that in the photographic illustration is the exact counterpart of the Black Hills Cambrian beds. He believes it to have been formed on a shingly beach. The writer would suggest that possibly many supposed conglomerates may be intraformational breccias[b] composed of limestone fragments, formed by crushing and recrystallization of matrix, as described, rather than by uplift above sea level.

SUMMARY OF DYNAMIC HISTORY.

The geologic map of the Sturgis-Spearfish quadrangles (Pl. I) shows a region of concentrated igneous activity about the city of Lead. This region is also a center of ore deposition, the sulphides and their derivatives being closely associated with the porphyries. The precious metals are known to occur in Algonkian schists, in the pre-Cambrian granitic eruptive rocks associated with those schists, throughout the Cambrain, and associated with laccolithic bodies. There are some productive mines in Siluro-Carboniferous limestones, and ores occur in the Tertiary porphyries themselves.

Structurally, the Lead eruptive center is an area of laccoliths in and below the massive limestones of later Paleozoic age and of dikes and stocks in upturned schists forming the conduits of sills in the thin-bedded Cambrian strata. From Custer Peak to Richmond Hill, where erosion has gnawed deepest into the eruptive region, stocks and dikes in schist are abundant. Surrounding this area the Paleozoic section shows sills in Cambrian strata, and laccoliths at the base of the great limestones.

It has been shown that the igneous intrusions of rhyolite and phonolite porphyries accompanied or immediately followed a great movement of uplift in

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[a] Weed and Pirsson, Judith Mountains of Montana. Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, Pl. LXX. Also, Little Belt Mountains. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, Pl. XXXIX.

[b] Walcott, C. D., Bull. Geol. Soc. America, vol. 5, pp. 191–195.

the area now occupied by the Black Hills.[a] This uplift arched the horizontal strata of the plains into an elongate dome; schists beneath, with nearly vertical bedding and lamination, moved up by faulting and slipping, frequently on planes of schistosity. Erosion has completely removed a portion of the sedimentary cover, exposing two kinds of sections whereby the solid geometry of structures within the uplift may be studied. One is a beveling across the top of the dome, exposing a ground plan; the other is a deep trenching by streams through the flanks, exposing vertical cross sections. The igneous matter rose through the steeply inclined schist laminæ and spread out among the sediments which lay across them unconformably. Erosion beveling has exposed dikes in the schist and flat masses in the later strata. The walls of erosion trenches show the thickness of the sills and lenses and sometimes their junction with feeding dikes.

The intrusives are confined to the northern portion of the uplift. The southern portion was occupied by massive ancient pegmatite granites, themselves pre-Cambrian intrusives in Algonkian strata. Probably they acted as a rigid cementing and hardening agent to prevent fracturing in the southern schists; the northern, less indurated phyllites cracked and faulted more readily to permit the younger intrusives to rise from the depths. The northern exposed schist areas contain many hundred dikes and some stocks; these must have induced movements of horizontal extension in the schist, and such movements are attested by bedding plane faults at the base of the Cambrian. The dikes have a common trend and dip parallel with schistosity. The dip gave them tendency to spread in the Cambrian in one direction more readily than in another. In Cambrian thin-bedded strata with many shale horizons sills formed in great number. Above lay the thick limestone; it resisted upward movement of the porphyries and locally became domed and arched. Beneath it were formed the principal laccoliths of larger size, the largest where the limestone was thinnest. Some of them were unsymmetrical, partly because they were injected into strata possessing an initial dip, partly because their conduits sloped and the magma was forced forward in one direction. On one side the limestone was flexed beyond the breaking point; a fracture opened and admitted the igneous fluid to higher horizons, forming subordinate laccoliths. The subordinate laccoliths are characterized by still greater lack of symmetry; their sides are steeper than those of the main laccolith; they fault and crumple the beds about them. Associated with dikes, sills, and laccoliths are breccias composed of fragments of the rocks through which the igneous magma passed. There is no evidence that the intrusives were connected with surface volcanics. In general the phonolites are younger than the rhyolites; none of the larger main laccoliths are formed wholly of phonolite; the phonolite broke through the larger bodies of rhyolite-porphyry and solidified in smaller

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[a] Jaggar, T. A., Laccoliths of the Black Hills: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, p. 280.

masses at higher horizons. The greater number of subordinate laccoliths, however, are of rhyolite-pophyry; these include Bear Butte, Deadman, and Whitewood Canyon laccoliths, Crow Peak, Inyankara, and Sundance Mountain. The magmas which formed the subordinate laccoliths were beginning to solidify and hence were more viscous; this is proved in part by fewer sills, by domes of smaller ground plan and greater convexity, and by diminution in total volume of intrusive rocks in the higher strata. The characteristic forward and upward movement of intrusive through strata is by way of strike fissures. The lower contact of sills and laccoliths frequently truncates or bevels strata obliquely across the bedding. The horizons, where a single stratum is followed for some distance, are composed of soft shale confined between harder beds.

Erosion has left laccoliths covered, partially uncovered, and deeply dissected, and in places has removed them entirely or left only scattered remnants. Conduit, basement contact, wedge, flank, crest—all parts of the laccolith are exposed, in plan and section, in different places in the Black Hills. The evidence quoted points to Eocene time as the age of intrusion. There were several thousand feet of strata above the laccoliths, and the soft Cretaceous shales absorbed laterally the doming produced by individual intrusive masses. Trunk drainage consequent on the Black Hills uplift was deflected by adjustment to the domed hard strata that were gradually uncovered; branch drainage, dependent on the relation of rainfall to form and texture of surface, continually changed with the discovery of hard and soft strata, producing hills in hard domed beds and annular valleys in soft ones. Such annular valleys were eventually superposed on porphyry, and persist in several deeply dissected laccoliths, such as Custer Peak and the Woodville Hills. Where an annular valley on the contact of porphyry and flanking sediments became superposed on the basement stratum, its course preserved approximately the outline of the laccolith after the same was in great part eroded away.

HISTORY OF INTRUSION.

The history of intrusion in the northern Black Hills is believed to be intimately associated with the history of the larger deformation. Intrusion is not conceived to have been in any sense a cause of the greater uplift, but an effect. The intrusions were a small incident in a great movement of elevation. The greater uplift probably took place after the close of the Laramie, along with similar movements in the Bighorn Range and the Rocky Mountains. Whatever their cause, these movements were colossal and involved a considerable section of the earth's crust; doubtless there had been similar movements about the hard granite core of the Black Hills from the earliest Paleozoic times. There was unquestionably some deformation prior to the laccolithic intrusions, for these broke across previously brecciated Cambrian flags and encountered dips already initiated. The post-Laramie uplift was accompanied by profound fracturing. The fractures reached downward to a zone where molten rock was under pressure. The liquid shot upward into every ramification of the fracture system; Algonkian, Paleozoic, and Mesozoic beds were in some sense under compressive stress, rising slowly, the hard, competent members supporting the arch, the soft beds following the lead of their more resistant neighbors. Diversity of structure and consistency produced minor differential movements of faulting and folding. The upturned schist beds slipped like cards on edge to make undulations in the basal Cambrian quartzite, which was also faulted in places. Springing into every weak place, spreading the beds and crumpling the soft ones wherever there was tendency to gaping by reason of the greater burden assumed by the more rigid strata, the igneous magmas reached the Cambrian through countless fissures in the schist beneath. The change in structure at the Algonkian-Cambrian unconformity was especially favorable to the development of local weakness that would give advantage to an igneous wedge. The Paleozoic horizon least compressed lay under the Carboniferous limestone. The thick limestone member, most "competent" to support load under lateral pressure, relieved the soft shales beneath in many places. The porphyry magma was itself probably under pressure and capable of independent dynamic action relative to individual beds invaded; whether that pressure was in any way limited by the actual volume of magma available, or what hydrostatic or thermal law governed it, we have no means of knowing, but it is quite certain that the pressure of igneous fluid relative to the condition of the limestone was sufficient locally to arch up and break through that stratum and some of the superjacent beds. That it did not do this until it was beginning to solidify is in part suggested by the fact that only a relatively small volume of porphyry broke through the limestone to higher horizons. The fact of local doming and fracturing of the limestone by the porphyry does not of necessity imply that the lava in each of those domes lifted the load; it bent and pimpled the limestone within an arch of enormously greater magnitude, composed of several competent members that were collectively supporting the total weight of sediments. The fact that the greatest doming of limestone over porphyry at the Terry-Polo complex took place where the limestone was thinnest shows that it was not the weight of superincumbent beds, but the inflexible quality of the thicker limestone which resisted doming. It is equally clear that the size of the laccolith is entirely independent of load; the smaller Ragged Top and the greater Deer Mountain laccoliths are both intruded at the same horizon; the Vanocker porphyry mass, probably the largest single laccolith exposed, reaches the Upper Carboniferous, while comparatively small subordinate laccoliths, like Crow Peak and the one in Whitewood Canyon, are intruded under Obolus beds at the base of the Cambrian.

DESCRIPTIVE GEOLOGY OF MINING DISTRICTS

A few typical sections, made from surface measurements of beds in stratigraphic succession among the ore-bearing horizons, will suffice to indicate the nature of the Algonkian and lower Paleozoic strata

ALGONKIAN

The two most striking Algonkian sections are those adjacent to the two largest ore bodies, namely, the Homestake and the Clover Leaf

SCHISTS SHOWING SYNCLINAL STRUCTURE NORTH OF HOMESTAKE MINE

A section from west to east on Deadwood Creek near Central shows the following Algonkian rocks

Just west of Central there is a contact of graphitic schist on the west with spotted mica-schist on the east, trending N 30° W Opposite Blackstone's house occurs a heavy ferruginous black schist with quartzite bands 1 to 2 inches wide cut by irregular white quartz bodies which form a distinct zone The sandstone bands clearly increase in size on approaching the De Smet open cut from the west Farther down the gulch, opposite the De Smet cut, ferruginous schist on the west is found in contact with gray mica-schist on the east, accompanied by a sudden change in dip The dip hitherto has been toward the east at high angles, but around the point in Sawpit Gulch the outcrops are all gray mica-schist, with a few very thin sandstone stringers and have a uniformly westerly dip This sudden change of dip just opposite the De Smet and Homestake ore bodies is significant and suggests that perhaps the great ore body may fill a synclinal saddle pitching to the southeast A short distance up Sawpit Gulch from Central, on the Columbus ground, a trench has been opened along a pyritiferous streak trending N 34° W This trench is directly in the line of the De Smet and Homestake workings

SCHISTS SHOWING SUDDEN CHANGE OF STRIKE NEAR CLOVER LEAF ORE BODY

East from Perry the Algonkian garnet schist strikes S 85° W, with marked lamination This trend is transverse to that of the Clover Leaf open cut southwest of here Eastward along the ridge on the north side of Elk Creek there is exposed garnetiferous mica-schist with numerous quartz lenses some of them folded, 1 to 6 inches thick The quartz shows rounded granules, it is difficult to determine whether they are cataclastic or sedimentary The lamination is wavy, trending S 50° W, but varying greatly in a single outcrop, even to north-south strikes Just south of this outcrop are crossed graphitic schists, ferruginous quartzite, and amphibolite with a trend of S 62° W

The next spur to the east shows to the north 80 to 100 feet of white quartz above with amphibolite trending west-southwest on the point of the spur Farther east is found a ledge of mica-schist with lamination N 52° W, and a white banding distinct from schistosity trending N 75° E The structure approaches a drawn-out linear parallel schistosity The white quartz zone is on the south, both on this spur and the next spur to the east, the southern extremity of the spur is occupied by a well-marked fold of mica-schist showing light and dark bands and pitching to the south Following out the ridge we come to an 80-foot ledge of ferruginous quartzite, showing contortions and jaspery texture On both sides of this salient reef occur great masses of amphibolite trending northeast-southwest, with southerly dip This dip is characteristic of the whole section There is here again a northwest-trending lamination distinct from the banding On the east of the little gulch to the north of this ridge occurs mica-schist with layers of micaceous sandstone Both lamination and bedding here trend N 10° W This northerly strike is repeated in the schists of Elk Creek Canyon, a short distance farther east

Summing up the Algonkian section along the ridge northeast of the Clover Leaf mine, we see that the west-southwest strike is unusual, suggesting that there is some sudden change in the structure east and west of the ridge in question This change, on the west, takes place in the immediate vicinity of the Clover Leaf ore body The section across the strike, from north-northwest to south-southeast, is as follows

Garnetiferous mica-schist
Graphitic schist
Ferruginous quartzite
Amphibolite
Mica-schist
White quartz
Mica-schist
Amphibolite
Quartzite
Amphibolite

CAMBRIAN, ORDOVICIAN, AND CARBONIFEROUS

The following tabulated sections show the characteristic details of the lower Paleozoic rocks, which are referred to on the foregoing pages, in the diagram (fig 1) and in the table of formations (p 20) The first of these sections is in the mining district near Terry Peak, the second is farther south near Englewood (the type locality for the Eocarboniferous limestone), and the third is on Bear Butte Creek, near the town of Galena, where the Deadwood and Englewood formations are well exposed in association with sills and dikes

TERRY PEAK SECTION.

Section in lower part of Cambrian terrane, Spearfish branch of the Burlington and Missouri Railroad, from northeast slope of Terry Peak to near Englewood.

	Ft	In
Ferruginous sandstone in 2-inch layers with green shale partings	5	0
Coarse, massive, ferruginous sandstone with olive-green shaly surfaces	4	0
Gray, fine sandstone, in places greenish, irregularly blotched with purple, and containing limonite Contains a few scattered worm borings	0	10
Limonitic earth	0	10
Very glauconitic, loose, ferruginous sandstone	5	0
Much decomposed siliceous sandstone, weathered locally to shales and hematitic earth	5	0
Gray, siliceous, chert-like, fine-grained, compact sandstone in beds of 2 to 4 inches	1	6
Single bed, gray, exceptionally siliceous sandstone, very little cement, some seams of limonitic earth	0	8
Fine-grained, dusty, glauconitic sandstone	0	8
Limonitic glauconite sandstone, less rusted than below, more siliceous toward the top Massive 3 to 4 inch beds	0	11
Massive glauconitic rusted sandstone	2	0
Massive rusted glauconitic sandstone in benches with a few interbedded shales	30	0
Altered flags and brown sandstone Dip, 12° NW	15	0
Coarse, brown, massively bedded ferruginous sandstone	2	0
Thin-bedded glauconitic brown sandstone	3	0
Cross-bedded brown ferruginous sandstone with fucoids	6	3
Thin-bedded, shaly, glauconitic sandstone with two or three 2-inch layers of brown sandstone	6	0
Very rusty glauconitic brown sandstone	1	0
Thinly laminated ferruginous sandstone with glauconitic layers	5	0
Same as above, in 3 to 5 inch beds	8	0
Same as above, very rusty, and in some places bedded in massive blocks	8	0
Brown sandstone with irregular 2 to 3 inch beds	20	0
Massive reddish and glauconitic sandstone	4	0
Thin, gray, shaly sandstone, highly glauconitic in places, weathering pink, purple, and blue.	9	0
Talus slope, showing three massive limestone breccia members, averaging 1 foot each	6	0
Thin-bedded limestone breccias	5	0
Gray, friable, sandy flagstones in thin ¼-inch beds	5	0
Paper shales and limestone breccias (intruded by porphyries)	40	0
Thinly laminated, fine, green-gray, shaly sandstone, more shaly below, sandy above	8	0
Shales with interbedded flagstone breccia, fine, gray-green, sandy parting beds among the shales decrease from here eastward	16	0
Paper shales with a few 2 to 4 inch beds of limestone breccia with trilobite fragments	5	0
Semicrystalline impure limestone slightly brecciated, divided into 4-inch bands of dark brown, red, and green	2	0
Paper shales with 1-inch limestone beds	3	0
Thin-banded semicrystalline limestone flags in ½ to 3 inch beds	3	0
Calcareous dark-brown semicrystalline sandstone containing obolus and trilobites (Dicellomus nana)	0	2

	Ft	In
Brown glauconitic and calcareous sandstone, parted by fine black slaty shales into layers one-half inch to 4 inches thick	1	6
Fine, gray-black, well-jointed paper shales, crumpled	5	0
Limestone flags containing limestone breccia, with two 2-inch beds of black slaty shales above and below	2	0
Rusty calcareous sandstone in 1 to 8 inch bands separated by layers of light-green shale, sometimes glauconitic, 1 to 3 inches thick. Both members are glauconitic, the sandstone more so than the shaly members	7	0
Rusty calcareous sandstone in beds 3 to 15 inches thick. Highly ferruginous, lemon-yellow to ocher colors and dark red brown. As a whole this coarse member weathers dark red	5	0
Much disintegrated red, brown, and yellow ferruginous sandstone. Small crystals of hematite, much limonite, veins of a carbonate and a manganese (?) mineral	0	10
Fine-grained limonitic quartzite, open structure, whitish, in beds 4 to 6 inches thick. Mineralized upper surface of basal quartzite	4	2
Eight to 10 beds, gray-green paper shales above, 4 layers of limestone flags below	6	0
Quartzite carrying trilobite shields and quartz in druses, upper surface red with scolithus borings	1	0
Pure siliceous sandstone, showing round grains and practically no cement, nearly a quartzite. Weathers rusty into massive beds and is slickensided, the slickensides show horizontal movement along a vertical plane	10	2
Quartzite blocks in talus below, carrying trilobite shields. This near base of basal quartzite of the Cambrian. The fauna is middle Cambrian. Talus of Algonkian schist	30	0

ENGLEWOOD SECTION.

In lower Paleozoic rocks, on Burlington and Missouri River Railroad, 2 miles southwest of Englewood.

PAHASAPA LIMESTONE

	Ft	In
Gray limestone shows a dip discordant with the Englewood limestone below and an unconformity on it along an almost horizontal line. Dip, W 28°. The Pahasapa beds at the contact are progressively truncated toward the north. The discordance is not wholly one of unconformability, because deformation at the south end of the cut affects both formations alike and there is probably some thrusting	250	0

ENGLEWOOD LIMESTONE

	Ft	In
Purplish limestones. At north end of cut dip is 35° to 50° easterly, at south end 27° S 80° E	50	0
Greenish-gray shales in railroad cut underlying the Englewood limestone. The shale is lumpy, light green on fresh surfaces, with dark-purple markings that show circular section across the bedding and linear, fucoid-like, cylindrical bodies on the bedding planes. As this almost certainly overlies the orange-colored *Zaphrentis*-bearing rock, it is probably Lower Carboniferous	14	0

ORDOVICIAN (?) OR ENGLEWOOD

[The following beds are from about the Ordovian limestone horizon downward, going north across strata dipping about 4° SSW., immediately under the great limestone quarry.]

Orange-colored arenaceous limestone bearing *Zaphrentis*, crinoid stems, and brachiopods, apparently in place

CAMBRIAN

	Ft	In
Talus	40	0
Green paper shales	10	0
Talus	80	0
Massive pink fucoidal limestone	0	40
Paper shales and calcareous flags	0	12
Ocher-yellow calcareous sandstone	0	26
Green paper shales	0	6
Arenaceous limestone with green shale surface, showing mud cracks with filling colored red	0	1
Massive hard arenaceous limestone	0	6½
Light-green paper shales and thin limestone flags, with irregular fucoidal surfaces and mud-cracks	0	17
Massive calcareous quartzite coated with calcite on joint surfaces Red on fresh surface, showing much crystalline carbonate	0	24
Glauconitic sandstone, laminated on cross-bedding planes, with fucoids, in part deep green and full of glauconite In other places dark red or limonitic yellow Some of the higher beds show *Scolithus* (?) borings Dip, 3° to 4° southerly	16	6
Very coarse, loose, and friable sandstone, with limonitic cement and some glauconite	0	3
Ripple-marked glauconitic and ferruginous sandstone, massive as a whole, but separated into ripple-marked slabs The slabs are coated with hematite. Evidences of disturbances, such as cross bedding and ripple marking, increase in the upper members of this section as a whole	0	20
Dark-green, glauconitic, arenaceous shale, very full of glauconite	0	3
Ferruginous sandstone in two massive beds, separated by a thin band of shale	33	0
Bright-red sandstone, probably the "Red Band" Carbonate occurs in veins and druses Limonite occurs in irregular spots, as well as, throughout the mass of the rock, a little glauconite. Rock is massive, showing some bedding lines and slightly wavy upper surface.	3	0
Glauconite shale. The bedding is here irregular and variable within short distances, cross bedding is common, this shale band thins out and is replaced by the red band above	0	10
Massive glauconitic sandstone. Variation in thickness is due to ridges resembling wave marks of 2 to 3 feet wave length and 2 to 3 inches height. Rock shows cross bedding	9 to 14 inches	
Glauconitic shale	0	7
Massive glauconitic sandstone	0	11
Arenaceous glauconitic shale	0	5½
Massive ferruginous sandstone, showing limonite, quartz, and red matrix Very little glauconite. Coarse cross bedding dipping SW, cut off N	0	21
Highly glauconitic and massive sandstone	0	10
Massive ferruginous sandstone, with a 12-inch quartzite bed below, showing quartz grains in a hematitic matrix and some glauconite The quartzite is massive while the upper members weather in 2-inch laminæ	3	0
Glauconitic sandstone in irregular laminæ, capped by a series of red ferruginous sandstones, showing no glauconite and much iron	4	2
Gray arenaceous shales and irregularly bedded glauconitic shaly sandstones	0	20
Glauconitic sandstone with very abundant glauconite, in two massive bands, with tendency to part on the bedding	0	14

	Ft	In
Massive ferruginous sandstone, showing less glauconite than in bed below	0	23
Massive glauconitic sandstone, showing cross bedding in places where the cross bedding laminae dip to the southward	0	13
Fucoidal, pink and green, loose soft, shaly, glauconitic sandstone In a distance of 6 feet this bed thins out completely and merges into the massive sandstone above	0	8
Glauconitic sandstone with pink and gray seams Weathers in massive brown blocks, 4 to 10 inches in thickness Dip, 6° SSW	3	0
Pink and green, fucoidal, loose, soft, shaly, glauconitic sandstone, with peculiar property of breaking up into many lentils on weathered surface, but showing a massive face	3	2
Massive glauconitic sandstone, showing many small wormy fucoid marks in cross section Upper surface coated with green shale which shows concave impressions of coarse ropy fucoids one-half to three-fourths inch in diameter, mixed with irregular lumpy masses	0	5
Thinly laminated green shale containing one band which is pinkish and sandy	0	1
Massive glauconitic sandstone, joint surface covered with globular and botryoidal coating of what appears to be a crystalline carbonate in white masses Cross section of lower part of this bed shows pink fucoidal markings Thins south and shows curved upper surface 4 feet long	3	5
Shaly glauconitic sandstone with abundant gray clay, lentiform fracture, fresh surface is greenish gray speckled with glauconite	0	19
Alternate massive bands of glauconite sandstone and gray shale The massive bands average 3 inches in thickness Seen on a fresh cut these beds appear as a single massive band	6	8
Fine-grained calcareous glauconitic sandstone irregularly banded pink and greenish gray The pink layers represent the fine-grained material of the ropy fucoid stems	0	4
Evenly laminated alternate layers of glauconitic sandstone, thin gray paper shales and pinkish sandy limestone flags varying in thickness from one-half inch to 3 inches The surfaces of these flagstones are covered with small ropy fucoids	0	15
Massive ferruginous glauconitic sandstone with small veinlets of carbonate, 2 conspicuous beds	2	0
Thinly laminated, very argillaceous, glauconite shale, green gray in color, with small wormy fucoids	0	5
Glauconitic sandstone with limonite occurring in streaks in cross section shaped like blades of grass Surface of a slab shows fucoids in depressions, and ridges like the mud-trails of a gasteropod	0	8½
Glauconitic shale with clay seams and grass-like fucoids in cross section	0	10
Coarse limonitic glauconite sandstone Massive, with some brecciation like the usual limestone breccias of the Cambrian	0	14
Speckled gray-green glauconitic sandstone	0	15½
Hard glauconitic sandstone, with predominant quartz sand All of this series of sandstones weather reddish brown with the gray-green colors in the shales	0	4
Irregular lentils of shaly glauconitic sandstone with much gray clay Fresh surface greenish gray speckled with glauconite	0	7
Very calcareous glauconitic sandstone with more carbonate visible under the hand lens than quartz Yellow clay on interlaminar seams Surface gray and red speckled, with some appearance of fucoids Evenly laminated in one-half to 1-inch bands	0	3½
Massive limonitic glauconite sandstone, highly calcareous, surface stained with iron streaks Fucoid impressions not pronounced	1	0

	Ft.	In.
Similar to next below, but more massive, with hematitic bands and fucoid curves shown in cross section	0	2
Loose shaly glauconitic sandstone, gray speckled with dark green. Breaks into irregular lentiform pieces with one 2-inch massive band. Much gray clay	0	6
Talus	0	6
Impure glauconitic sandstone, calcareous and argillaceous. Fucoidal surfaces. A massive bed, with a minute clay-seamed lenticular structure	0	10
Talus	1	0
Coarse glauconitic sandstone, showing under the lens abundant transparent rounded quartz grains, with interstitial smaller grains of limonite and glauconite. Parallel to the stratification there are bands of more abundant glauconite and some crystalline carbonate. The whole bed is massive with some interlaminar slickensides	0	15
Similar to the bed below, with greenish-white clay on fracture surfaces. There are small fucoids and some appearance of flat "pebbles," or breccia fragments, indicating proximity to the horizon of limestone breccias. Laminæ one-half to 1 inch thick	0	7
Massive speckled glauconitic sandstone, purplish on weathered surface, with pinkish spots. Variegated color on fresh surface. Whole series here is more or less fucoidal	0	6
Railroad cuts north of this point show fragments of the glauconitic series. Lowest bed exposed glauconitic shale. Apparent dip, 9°, S. 27° W.		

GALENA SECTION.

Section in lower Paleozoic rocks, up Bear Butte Creek from road junction east of Galena.

ENGLEWOOD LIMESTONE.	Ft.	In.
Massive limestone of grayish-yellow color with blotches of purple hematite that frequently form a coating on the fossils found in this bed; some calcite druses. Dip, 8°, N. 70° E.	8	9
Alternating speckled yellow and pink bands of friable thinly laminated limestone, with much crystalline calcite	3	5
More massive purple limestone; 40 feet above is the base of the cliff of Pahasapa limestone	1	6
Massive purplish and yellow beds, above a cliff of Whitewood limestone	4	4
WHITEWOOD LIMESTONE (ORDOVICIAN).		
Massive gray limestone, spotted yellow; irregular, with lenticular laminæ produced by weathering	15	0
Buff-colored sandy limestone becoming increasingly siliceous downward; massive, weathering to thin laminæ	6	0
CAMBRIAN (DEADWOOD FORMATION).		
Yellow and gray limonitic calcareous sandstone	2	0
Massive brownish sandstone, with traces of scolithus borings	0	10
Hard, white, *Scolithus* quartzite, with well-marked gasteropod borings thinning to the west	0	1
Brown sandstone	0	4
Hard white quartzite, *Scolithus* borings in upper surface, thinning toward the west	0	4¼
Pink and orange-colored quartzite	0	2
Shale	0	½
Pink quartzite varying to white, without borings	0	1
Pink sandstone	0	4

	Ft.	In.
White quartzite	0	1
Pink and yellow fine-grained sandstone. All of these beds show a tendency to converge westward	0	9
White quartzite	0	½
Pink sandstone	0	2
White quartzite	0	2½
White quartzite, weathering reddish on its upper surface	1	2
Yellow quartzite, weathering pink	1	4
Pink, yellow, and white sandstone, becoming more calcareous downward	6	0
Gray calcareous shales, becoming thinner bedded and more shaly downward, with fine gray slaty shales at the base; scolithus borings occur throughout this series	6	0
Persistent white sandstone beds showing ripple marks in cross section, and veneered on its upper surface with gray shale carrying fucoids	0	6
Brown shales with light-green surfaces and interbedded gray shales, showing ropy fucoids	0	2
Cliff of massive brown sandstone, with glauconite beds on the south side of the creek. Dip due E., 8° on the E., 20° on the W	25	0
Brown ferruginous sandstone, very glauconitic above and massive; below the rock becomes more laminated and contains less glauconite. Dip, 8° due E	8	11
Massive dark-brown sandstone forming a single bed, with siliceous infiltrations	4	3
Glauconitic sandstone, with a more thinly laminated middle band	3	10
Pale rose-colored sandstone, as below	0	8
Massive brown sandstone	1	1
Pale rose-colored, thinly laminated, shaly sandstone, with gray fucoids. This series seems to be thinning toward the west, and shows in that direction increasing shaly lamination	0	11
Brown sandstone	1	1
Brown sandstone filled with yellowish fucoids	1	9
Strongly glauconitic hard sandstone	0	8
Yellow and green shales, with fucoids and glauconite	0	4
Soft rotten glauconitic shale	0	1
Hard glauconitic quartzite	0	9½
Soft shales	0	6
Speckled brown and green sandstone, with glauconite	1	0
Thinly laminated glauconitic shale, with fucoid markings of yellow limonite. The whole series of rocks here is calcareous	0	10
Massive red-brown sandstone, very ferruginous, with some glauconite	5	0
Ocher-colored fucoid shale, with black blotches and thin films of green shale	0	8
Glauconite shales, thin bedded, showing coarse ripple-marked surfaces covered with limonitic fucoids of ocher color	4	7
Bright-green massive glauconitic sandstone	0	10
Ocher shales	0	5
Hard glauconitic sandstone, apparently thinning westward, with small yellow fucoid markings	0	4½
Glauconitic fucoid shale, thinly laminated	3	10
Yellow and green shale with large grains of glauconite	0	3
Thin-bedded glauconite shales	60	0

	Ft.	In.
Light-gray quartzite, with ocher-colored cement and fucoids and entirely without glauconite. This absence of glauconite very conspicuous in contrast with adjacent beds	0	8
Red, ferruginous, shaly limestone, carrying crystalline calcite, hematite, yellow fucoid traces, and near the base thin green lenses, slightly glauconitic, covered with fucoids	2	10
Similar to above, but more massive	3	0
Thinly laminated, light-brown, dolomitic shale, with some glauconite; weathers red on edges	3	0
About 40 feet below this the gray shaly dolomitic limestones outcrop in thin continuous laminated flagstones. The surfaces show fucoids, mud cracks, and glauconite, and there are interlaminated limestone breccias or "intraformational conglomerates."		

TERTIARY AND QUATERNARY.

The Tertiary and Quaternary formations have an indefinite thickness, occurring, as they do, only in the form of eroded remnants. Tertiary occurs as white clay in the basin where Lead has been built and in the saddles between neighboring hills. This clay contains fossil vertebrates, and also fragments of porphyry, hence is the product of erosion after the porphyries were intruded. This is further proved by the fact that the clays are deposited in a topography eroded far below the present porphyry summits. The material here called Quaternary consists of rounded stream bowlders and gravel, occurring in masses sometimes 50 to 100 feet thick, usually filling divides between the present streams. These remnants show the location of more considerable deposits of the same sort along ancient stream channels. The courses of these ancient streams in several cases show a significant relation to elbows of capture and valley trends which mark the changes the drainage has undergone.

The thickest masses of Quaternary gravel lie at the head of Boulder Creek, east of Deadwood, on the divide southeast of Crook Mountain, at the head of Park Creek, on the divides west and southwest of Sheep Mountain, and at the head of Whitewood Creek, along the Burlington and Missouri River Railroad. There is reason to suppose that these ancient stream gravels may contain placer gold, but they have not been worked to any extent, as compared with the gravels of the present gulches.

ECONOMIC RESOURCES OF THE NORTHERN BLACK HILLS.

Part II.—MINING GEOLOGY.

By J. D. IRVING and S. F. EMMONS.

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ILLUSTRATIONS IN PART II.

ECONOMIC RESOURCES OF NORTHERN BLACK HILLS.

PART II.—MINING GEOLOGY.

By J. D. Irving and S. F. Emmons.

INTRODUCTION.

This paper is intended to embody a description of the economically important ore deposits in the Sturgis and Spearfish quadrangles, in the northern Black Hills. Inasmuch as this area includes the major portion of the mineralized and productive territory, and as those few ore bodies that fall without its limits have been described, the title has been expanded to cover the mining region of the northern Black Hills. The tin and gold ores of the southern hills are not included. The work is chiefly of a descriptive character, and theoretical discussions are either excluded or made as brief as possible. Generally the discussion of each class of deposit is preceded by a general statement of most of the important facts embodied in the more detailed description, so that the essential facts may be readily grasped.

Acknowledgments.—The field work upon which the mining portion of this paper is based was carried on during the field season of 1899. The work was done by Mr. J. D. Irving under the direction of Mr. S. F. Emmons, who has written the report on the Homestake mines. Valuable assistance was rendered by Messrs. J. M. Boutwell and P. S. Smith. Conjointly with the investigation of the mines, the areal geology was studied by Dr. T. A. Jaggar, under whose personal direction the field operations were conducted and to whom the writers are indebted for many valuable criticisms and suggestions.

It is with great pleasure that the writers acknowledge the uniform courtesy with which the owners and operators of the mines of the northern Black Hills have placed at their disposal information and facilities for investigation indispensable to the preparation of the work. Acknowledgments are especially due to Messrs. T. J. Grier, of the Homestake Mining Company, Angus R. McKay, C. W. Carpenter, and Colonel Franklin for their endeavors to further the work carried on in their mines. Many valuable suggestions are also due to the kindness of Dr. F. R.

Carpenter. It is impossible to make special acknowledgments to all from whom courtesies and assistance were received, but of such as have not been separately mentioned too much can not be said in return for the aid which has been so willingly rendered.

Location of the mining region.—The main productive mining region of the northern Black Hills is included within an area of about 100 square miles. It extends from the town of Perry, on Elk Creek, northwestward to the town of Carbonate, on the east bank of Spearfish Canyon, while its widest as well as its most productive portion lies between Terry Peak on the southwest and Garden on the northeast. Outside of this area is a small and comparatively undeveloped district to the west in the vicinity of Nigger Hill.

Within the main mining region occur many and very diverse types of ore deposits, some of which occur mainly in the rocks of the older geological formations. These deposits in each case have features characteristic of the geological formation in which they occur, so that for purposes of description they may be most logically classified under the head of these geological formations. In this way the following five main divisions may be distinguished: (a) Ore deposits in Algonkian rocks, (b) ore deposits in Cambrian rocks, (c) ore deposits in Carboniferous rocks, (d) ore deposits in eruptive rocks, (e) ore deposits in rocks of recent formation.

The relations of these different groups of ore deposits to the rocks of the several formations of the Black Hills are shown in Pl. V (p. 214) and fig. 1 (p. 18).

CHAPTER I.

ORE DEPOSITS IN ALGONKIAN ROCKS.

The ore deposits occurring in the metamorphic schists and other rocks of Algonkian age constitute the most important as well as most permanent factor in the mineral production of the northern Black Hills.[a] They may be subdivided into gold ores, copper ores, and tin ores.

GOLD ORES.

Of these three divisions the first, or that of the gold ores, has thus far been the only one of importance. There are three mines that have yielded ores—the Homestake mine, the Clover Leaf mine, and the Columbus mine. Pl VI shows the location of the Algonkian lodes and their relation to the stratigraphy.

HOMESTAKE MINES.

By S. F Emmons

The Homestake belt of mines extends from the town of Lead and Gold Run Gulch northwestward across Bobtail Gulch to Deadwood and Sawpit gulches, covering thus an area over a mile in length and about 2,000 feet in width.

The gold product of this group of mines has always overshadowed that of all the other mines of the Black Hills together. For a long time it constituted about 90 per cent of the total product of the hills, although it was somewhat less in the early days, when placer mines were more productive. Since 1890, however, with the increasing development of the siliceous ores of the Cambrian, this proportion has gradually decreased to 60 per cent, in spite of the fact that the actual product of the belt has steadily increased.

DISCOVERY AND DEVELOPMENT.

DISCOVERY.

For many years reports had been current among Western pioneers and prospectors of the occurrence of gold in the Black Hills, reports that became unduly

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[a] None of the ore deposits of what is known as the southern hills are included in this treatment, as they are entirely without the area mapped This will account for the omission of many of the now quite important gold-producing properties that occur south of the town of Perry

magnified for the very reason that they could not be verified because of the jealous care exercised by the Sioux Indians in keeping miners and prospectors from this the most valued portion of their great reservation, which, by the treaty of 1858, comprised all of South Dakota lying west of the Missouri River. These reports were, doubtless, mainly founded on the story of Father de Smet, a Jesuit missionary of Belgian birth, residing among the Sioux in the first half of the nineteenth century. He stated that nuggets of gold that came from the Black Hills were shown him, and that he was assured that there was a mountain of gold where the nuggets came from. Subsequent investigation proved that the Indian mountain of gold was nothing more than a formation of yellow mica; but this probably found fewer reporters and believers.

The military reconnaissance by General Custer in the summer of 1874, which actually penetrated the hills, was accompanied by a geologist (Prof. N. H. Winchell) and several miners and prospectors, and actually did discover gold in the stream beds of the Harney Peak region. After the return of the expedition the miners who had accompanied it organized a party supposed to be strong enough to protect itself against the Indians and established themselves in a stockade on French Creek. Under the treaty of 1858 the Government had bound itself to protect the reservation against the encroachment of white men, so this party was brought back to Fort Laramie by a company of United States cavalry in March, 1875. Steps were taken to prevent the inrush of miners which seemed likely to follow, it being generally understood, however, that the Government would take the necessary steps to secure a recession of the hills by the Indians so that they might be thrown open to peaceful and legal occupation.

As some doubt was felt by persons of high authority whether gold did exist there in remunerative quantities, the Secretary of the Interior authorized a geological examination of the hills to determine the true facts regarding the nature and value of the mineral deposits. Accordingly, the geologists, W. P. Jenney and Henry Newton, with a strong military escort, were sent there in May, 1875. This expedition, whose final report for various reasons was not published until 1880, made a less thorough examination of the northern part of the hills than of the region farther south, where gold was first discovered, because the northern portion was so thickly covered with forest growth as to render it almost inaccessible.

The region of the Homestake mines was not even reached by the party of Newton and Jenney in 1875, but some of the men attached to this party remained behind to prospect after it was broken up for the winter. The first mention of the region in print is found in a letter from T. H. Mallory to W. P. Jenney, dated January 31, 1876.[a] Mallory stated that he had found abundant gold in the gravels

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[a] Newton, Henry, and Jenney, W P, Report on geology and resources of the Black Hills U S Geog and Geol Surv. Terr, 1880, p 282

of the various streams around Whitewood and Deadwood gulches, and characterizes the region as the best place in the hills for a poor miner.

The Homestake and Old Abe deposits are said to have been discovered in April, 1876, by two French boys, Moses and Frederick Manuel. The Highland, Golden Star, and other claims now included in what is known as the Homestake belt were located later in the same year. During that summer the work was mainly that of the prospector. At the surface was found a great extent of iron-stained rock (chloritic slates, quartz, and porphyry) which carried gold, sometimes as much as $16 per ton, but in general of much lower grade. Although it was difficult to make such determination of the form or boundaries of the ore bodies as would give an idea of their probable value or permanence, yet public expectation had been so excited with regard to the assumed mineral worth of the hills that four of these claims found purchasers within the year at prices varying from $30,000 to $165,000. In 1877 they were examined and reported upon by such well-known and experienced mining engineers as William B. Farish, Louis and Henry Janin, and Augustus J. Bowie, jr., in the interests of prominent mining operators and capitalists, among whom were J. W. Gashwiler, George Hearst, J. B. Haggin, and Lloyd Tevis.

At the time these examinations were made the developments consisted only of open cuts, or shafts not over 50 feet in depth, yet by the following year the various claims within the belt had been purchased and four large gold-mining companies had been organized and were in active operation. Three—the Homestake, the Father de Smet, and the Highland—had been incorporated in California, and one—the Deadwood-Terra Company—in New York. Their properties were comprised in a belt about 1½ miles long, extending in a northwesterly direction from Gold Run on the south to Deadwood Creek on the north. The group of claims constituting the Homestake mine occupies the southern end of the belt and is succeeded on the north by the Highland, Golden Terra, Deadwood, and Father de Smet mines, in the order named. Not long after the mines were opened it was found advisable to work them under a single management, and as time went on the Homestake Company came either into control or into actual possession of the other properties in a manner and to an extent not generally known to the public. The result has been that the name "Homestake" has been applied to the whole belt and the other properties are often spoken of as if they were simply parts financially, as they are geologically, of one great property. This practice will be followed here, except so far as it has been possible from accessible published reports to segregate the bullion output of the different companies.

The history of the Homestake properties, could it be given in full from 1878 until the present day, would be a most instructive one. It would describe the development of very low-grade bodies of ore in the face of great natural obstacles, and with a margin of profit necessarily so small that a very slight error might turn it into a loss; yet the company has been so uniformly successful that at no time has it been found necessary to suspend the regular monthly dividends to stockholders. As it has been the policy of the company not to make public anything more than the general financial results of its business, the published data with regard to it are so incomplete that it is only possible here to give a general sketch of its history; which may not be strictly correct in all its details.

In a large degree the uniform success of the properties has doubtless been due to the fact that those who furnished the capital for their development were men of practical experience in the management of large mining enterprises. Both in purchasing and developing their property they took the best scientific advice, and were willing to spend money freely in accordance with this advice. Furthermore, after having convinced themselves that their manager at the mines was a man of ability and integrity, they gave him free hand and did not hamper him in his work. To the two men who have had the entire management of its affairs since their inception, Samuel McMaster up to 1885 and T. J. Grier since that time, is due a great part of the credit for the remarkable success of this mine.

REDUCTION OF ORES.

It was evident that for a profitable working of such very low-grade ore as was found here it was necessary to handle very large quantities and at very low cost. It was possible to mine at very low cost, for the ore bodies, lying on rather steep hill slopes, could be worked in open cuts or actually quarried. The ore, moreover, was free milling and of a nature to be very readily crushed, hence the proper way was to increase the mill capacity as fast as was consistent with successful working and a judicious expenditure of capital. Timber was abundant in the hills, though it had been cleared away or burned off from the immediate vicinity of the mine. Other supplies had to be hauled from the Union Pacific Railroad, or from the Missouri River, a distance of 200 to 400 miles.

In the summer of 1878 two stamp mills, one of 80 stamps at the Homestake mine, and one of 100 stamps at the Father de Smet, were put in operation. In 1879 the Homestake Company had a second mill of 120 stamps running, and mills of 80 stamps each were built at the Deadwood and Caledonia mines. In 1880 the Highland mill of 120 stamps and the Terra mill of 80 stamps were added, making at the close of that year a total of 740 stamps employed in crushing the ore from this belt, with an actual capacity of 2 to 3 tons each per twenty-four hours.

According to the first report of the Homestake Company, which gives an account of the operations for twenty months up to September, 1880, the average yield of the ore had been $9.69 per ton up to June, 1879, but when all the ore between the walls was taken without sorting, thus decreasing the cost of mining, this yield was reduced by $3 to $5 per ton. It increased again later, when higher grade ore was found in the 100-foot level, to $7.65;[a] meanwhile, the cost of milling had been brought down to 90 cents per ton in the 80-stamp mill, and 71 cents in the 120-stamp mill. To bring about such low costs it was quantity rather than quality of work that had been aimed at; blankets and concentration machinery were not employed, because on the concentration of the small amount of pyrite contained in the ore it was found that the pyrite assayed only $8 per ton, hence was not richer than the ore. Moreover, by an assay of the tailings, it was found that the mills were extracting 75 to 80 per cent of the gold in the ore, which was a satisfactory yield under the circumstances.

In an ore of this character it is impossible to distinguish by the eye alone that which will pay to mill from that which will not, and the practice has been adopted of panning each day a 2-pound sample of ore from every fresh face in the mine. Power is used to manipulate the pestle, which reduces the fragments of ore to a sand fine enough to be easily panned, and the man who does the panning has by long experience acquired such skill that he can pan 60 samples per day and estimate their value by the eye within 25 to 50 cents. These estimates are checked from time to time by fire assays of the rich sands left in the pan. Although this method of valuation appears very crude, it has the sanction of twenty years' practical experience, during which it has evidently given satisfaction to those employing it.

The mill capacity of the Homestake Company, which had an aggregate of 200 stamps in 1879, was increased as time went on by the enlargement of existing mills and the acquiring of new ones, until, as the report of 1898 shows, there were, on May 1 of that year, 540 stamps dropping on Homestake ores alone. The Father de Smet and Caledonia mills, with an aggregate of 160 stamps, had long since ceased working, as no more ore was being produced from those mines and they were not readily accessible from Lead, which the southward pitch of the ore rendered the most central point in which to concentrate the work of the mines.

As greater depths were attained in the mines the amount of unaltered pyrite in the ore increased somewhat, though not as much as in most mines, and although the management still claims that these sulphides contain no more gold than the average of the ore, it is evident that it was not considered good policy to neglect this part of the product, whose gold was not extracted by amalgamation. The concentrates from the mills were sold for a time to the pyritic smelter at Deadwood, and to the chlorination works at Pluma, while a small cyanide plant had been erected by the company for experimental work. It is significant that, as is shown by the report of 1900, another large cyanide plant of 1,200 tons daily capacity was building by the company and expected soon to be in running order.

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[a] Further details as to yield of ore will be found in tables given on page 63.

The number of tons milled has increased annually from less than 200,000 in the early years to nearly 900,000 in 1900, but the costs chargeable to milling, as well as can be determined from the financial statements in the reports, still amount to about 80 cents per ton in round numbers.[a]

MINING DEVELOPMENT.

The erosion of Deadwood, Bobtail, and Gold Run gulches had made cuts 250 to 400 feet below the base of the Cambrian beds, or the highest points of the ore remaining on the intermediate ridges, and as the slopes of these ridges were quite steep the first mining was done by open cuts or quarries; then tunnels were run on a level as near the bottom of the gulch as was practicable and the ore dropped through chutes into cars in the tunnels. On either face of the porphyry-capped ridge between Deadwood and Bobtail gulches, which cut across the mineral bed nearly normal to its strike, the quarries exposed rock faces about 200 feet in height, which afford admirable opportunities for studying the structure of a mineralized rock. Between the Highland shaft and the Star shaft of the Homestake mine, where the ravine runs approximately with the strike of the ore belt, is the greatest open cut in the region. This cut is about 800 feet long and 200 to 300 feet deep, its bottom being 100 feet below the collar of the Star shaft. On its sides, also, there are good rock sections which show the porphyry bodies coming up through the slates and spreading out in horizontal sheets between the Cambrian beds. As an instance of the scale on which these quarries were mined in the early days, the record shows that in 1882 a mass of mineralized rock 100 feet long by 70 feet wide and 100 feet deep—say about 5,000 tons—was broken down by a single shot. There was necessarily a limit in depth to which this method of mining could be carried, and vertical shafts have subsequently been sunk at various points within the belt, from which levels, at vertical intervals of about 100 feet, run out under the quarries.

As will be shown later, the ore bodies pitch rather rapidly to the south; hence the northernmost mine, the Father de Smet, was the first to reach the bottom of the pay shoot, and this mine ceased producing in 1886. On the other hand, the Homestake properties at the southern end of the belt have not yet reached the bottom of the shoot, the Golden Star, or central shaft, being now 1,100 feet deep. A new shaft, the Ellison, is being sunk about 1,000 feet south of the Star shaft on the south side of Gold Run, and is intended to be used for working the lower portion of the ore belt on its southern extension beyond where any ore shows at the immediate surface. In working the great bodies of ore it is often necessary to leave chambers several hundred feet in length and width, and the Comstock system of square sets of timbers, or else huge timber cribs filled with waste rock, are used

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[a] These figures are obtained by dividing the gross amount of expense assumed to be chargeable to milling by the number of tons milled. Doubtless the costs might be figured considerably less if they were strictly confined to the actual running cost of each mill.

to support the roof and walls. In the Homestake mine the waste rock is taken from the bottom of the great open cut and sent down to the stopes through a shaft or rock chute. It is evident that mining costs must increase with depth attained. On the other hand, the increased cost has been offset in a measure by improved transportation facilities, which have lowered the cost of supplies of all kinds. The amount of water in the mines is not excessive, except in the spring, when the melting of the snow sends a considerable amount down through the open cuts. It is not, however, a disadvantage to the mines, since it can be used in the mills, for one of the principal costs in milling operations is that of obtaining a sufficient supply of water.

The actual cost of mining per ton of ore milled is not known to the writer, but the aggregate cost, as taken from figures given in the Homestake reports, and counting in all mining work, exploratory as well as the direct cost of extraction, would appear in late years to have been a little over $2 per ton, whereas in the report of September, 1880, it was given as $1.33, or, calculated on the above basis, $1.70.

MEANS OF COMMUNICATION.

As has already been stated, when the mines were first opened the nearest rail or water communication was by the Missouri River, about 200 miles distant, or the Union Pacific Railroad, about 400 miles distant. As wood was used for fuel as well as for mine timbering, a large amount was necessarily consumed, and the company soon began the construction of a narrow-gage railway, which at first only ran from the mine openings to the mills, but was later extended through the timber belt in the direction of Rapid; 25 miles of this road was completed by 1882. By 1886 the Fremont, Elkhorn and Missouri Valley Railroad, now a part of the Chicago and Northwestern system, was within 50 miles of Rapid, and in 1887 had reached Whitewood. About this time, however, the tenor of the Homestake ores was falling off, and they were carrying 7 to 10 per cent of sulphurets, which did not amalgamate, and hence yielded nothing. This probably accounts for the slow progress of the various roads in the immediately subsequent years. By 1890, however, prospects were better in the mines; the Chicago and Northwestern Railway had reached Deadwood, and the Burlington and Missouri River Railroad, coming up from the south, had reached Hill City on its way to the same point; a narrow-gage railway connecting Deadwood with Lead had been built, and the Homestake Railroad had been extended to Piedmont, on the line of the Chicago and Northwestern Railway; a pyritic smelter had been built at Deadwood, and a large chlorination plant at Pluma.

Since 1891 there have been two rival trunk lines, the Northwestern and the Burlington, competing for the mining business of the Black Hills, and spurs have been built to every mine of importance, so that in the last decade transportation charges have probably been much lower than ever before.

Water has always been a considerable item of expense with the Homestake Company because of the large amount required for their stamp mills. It early acquired all the sources of water supply in the neighborhood; then a water company was organized, which constructed pipe lines and ditches to the heads of the nearest streams, and finally to the head of Spearfish River. This company, together with the Homestake Railroad, which was also organized as a separate company, has recently by consolidation been merged into the Homestake Company.

PRODUCTION.

The following table, made up from data contained in the financial reports of the Homestake Company, gives its production from January, 1878, to June, 1900, together with the amount of dividends distributed to stockholders. The record speaks of only one assessment, of $200,000, which was apparently the total outlay of cash for developing the mine and putting it on a paying basis. In the twenty months' period from January, 1878, to September, 1880, $600,000 had been paid in dividends, and $1,465,675 for plant and working expenses, leaving a balance of $107.48 in cash on hand. Cost of plant is charged as $503,475.

Production of the Homestake Mining Company.

Year ending.	Ore milled.	Bullion.	Gold.	Silver.	Total value of gross product.[a]	Dividends.
	Tons.	*Ounces.*				
June 1, 1881[b]	411, 358	167, 861	$2, 801, 026	$29, 436	$2, 831, 890	$990, 000
June 1, 1882	180, 514	72, 920	1, 222, 400	13, 366	1, 237, 161	422, 500
June 1, 1883	179, 074	70, 341	1, 183, 689	12, 545	1, 196, 394	600, 000
June 1, 1884	191, 505	67, 776	1, 142, 599	11, 898	1, 154, 681	400, 000
June 1, 1885	213, 190	72, 347	1, 224, 484	12, 468	1, 236, 967	343, 750
June 1, 1886	219, 165	76, 592	1, 294, 960	12, 029	1, 306, 989	612, 500
June 1, 1887	219, 290	56, 173	950, 343	8, 189	958, 532	450, 000
June 1, 1888	243, 355	52, 737	895, 822	7, 585	903, 407	300, 000
June 1, 1889	285, 774	56, 846	961, 907	8, 117	970, 744	275, 000
June 1, 1890	267, 557	58, 356	980, 243	8, 597	988, 840	150, 000
June 1, 1891	319, 130	65, 987	1, 110, 361	11, 115	1, 121, 476	150, 000
June 1, 1892	321, 495	72, 630	1, 217, 958	11, 106	1, 230, 546	150, 000
June 1, 1893	294, 530	66, 905	1, 118, 602	9, 347	1, 127, 949	150, 000
June 1, 1894	309, 210	82, 665	1, 371, 568	9, 341	1, 398, 850	181, 250
June 1, 1895	330, 020	90, 991	1, 508, 049	9, 397	1, 546, 138	318, 750
June 1, 1896	245, 220	69, 322	1, 156, 785	8, 099	1, 177, 616	375, 000
June 1, 1897	395, 530	110, 851	1, 840, 674	13, 112	1, 899, 725	375, 000
June 1, 1898	548, 390	149, 283	2, 467, 997	15, 377	2, 518, 026	500, 000
June 1, 1899	620, 479	172, 543	2, 667, 281	18, 559	2, 725, 196	750, 000
June 1, 1900	891, 585	227, 695	3, 557, 387	26, 338	3, 658, 956	1, 175, 000
Total	5, 685, 771	1, 870, 719	30, 674, 132	256, 019	31, 190, 083	8, 668, 750

[a] The figures in the column "gross product" are slightly in excess of the sum of those in the "gold" and "silver" columns, because they include the premium of exchange, and in the last six years also the amount received from sale of concentrates.

[b] From January, 1878, to June 1, 1881.

The following table gives the average yield of ore per ton milled at different annual periods during this time. There are no data from which to determine accurately what the actual content of the ore was, or what the loss has been. The method followed of assaying the tailings from time to time is not entirely accurate, for it does not take into account what loss there may have been of float gold, which, as its name indicates, would have floated off with the water and not settled with the tailings, and hence in such an ore might have been considerable. The table also gives for the same period the relative portions of gold and silver in the bullion produced, both by weight and by value.

Average yield of ore and relative proportions of gold and silver.

Period	Average yield of ore treated	Fineness of bullion	Ratio of gold to silver in bullion.	
			By weight	By value
	Per ton			
Up to September, 1880	$6.90	815.1	4.90 to 1	96.4 to 1
June, 1881, to June, 1882	6.85	808.6	4.64 to 1	94.3 to 1
June, 1882, to June, 1883	6.60	808.0	4.60 to 1	91.4 to 1
June, 1897, to June, 1898	4.60	793.0	4.29 to 1	160.0 to 1
June, 1898, to June, 1899	4.40	758.0	3.98 to 1	143.0 to 1
June, 1899, to June, 1900	4.10	770.0	3.88 to 1	135.0 to 1
Total product to June, 1900	5.485			119.81 to 1

It is claimed by the management that there is no appreciable falling off in the tenor of the ore with depth, yet the above figures seem to show a remarkably uniform decrease in its average yield. It must be admitted, however, that these figures are not necessarily conclusive. During the first three periods the ore would naturally have been somewhat richer than that found at greater depths, because it would have been enriched by the oxidizing action of surface waters. For the last three annual periods it is necessary to remember that the number of tons treated has been increasing very rapidly, and it is very possible that the average yield has been lowered by the milling every year of a larger amount of low-grade rock. It is quite possible, moreover, that when the company treats its own concentrates there may be a saving that may sensibly increase the average yield of its ore. As yet it can not be said that there is any conclusive evidence of a decrease in value with depth in the sulphide or unaltered zone.

The other columns in the table were arranged for the purpose of determining whether there was any uniform change with depth in the proportions of gold and silver in the bullion. For this purpose the figures in the last column are of no value, since they are based on the commercial value of an ounce of silver, which has been too variable to make it worth while to reduce it back to a common unit.

The others are deduced from proportions of gold and silver which are tabulated in the reports for each bar of bullion. In this case the average during one or more selected months has been given to represent the character of the bullion during the year. The bullion is remarkably free from impurities other than silver, the average of such impurities being less than 2 per cent, the ore yielding about 80 per cent gold and 18 per cent silver.

In considering the earlier and later groups of years the decidedly larger ratio of gold in the upper over the lower levels would be accounted for by the superior solubility of the silver, in consequence of which a larger proportion would have leached out, but in the last three years in the lower levels there appears to be a slight, though not absolutely certain, tendency for the proportion of silver to still continue to increase. It will be of interest to observe in the future whether this tendency still continues with greater depth.

The next table gives the total yield of all the mines of the belt up to June, 1900, from figures kindly furnished by the officers of the Homestake Company. The dividends paid in the same year are also given, as far as it has been found possible to ascertain them; but it is evident that they are not complete, especially in the case of the Highland mine.

The product of the Columbus mine should be added to the total, as it forms part of the belt. Its amount is, however, not known. The United States Mint returns for 1891, 1892, and 1893, give an aggregate of $88,618.41 for this mine; for other years its product was not segregated.

Total product of the Homestake belt up to June, 1900, with relation of product to dividends.

Name of company.	Product to June 1, 1900.	Dividends in same period.	Per cent of product.
Homestake	$31,190,143	$8,668,750	27.7
Deadwood-Terra (ceased in 1898)	11,073,065	1,500,000	13.5
Highland	12,018,610	....	....
Father de Smet (ceased in 1886)	3,259,383	1,110,000	34.1
Caledonia (ceased in 1893)	2,345,621	194,000	8.3
Total	59,856,822	11,472,750	....

The dividends of the Homestake and Father de Smet mines are probably correct. It will be noticed that the percentage of dividend to product is greater in the case of the latter than in the former. This is due, probably, to the fact that the De Smet mine worked only on the richer ores near the surface, which have been more easily milled than those of the Homestake. No attempt has been made to calculate the percentage of dividends to product for the whole belt, inasmuch as it is evident that the Highland mine must have paid some dividends and probably of similar ratio to the Homestake, but it is not known what they were.

It may be instructive to compare the results obtained in working this mine with those of some mine of an opposite type, whose ore instead of being exceptionally low grade is unusually rich. For this purpose the Portland mine, of Cripple Creek district, Colorado, has been chosen, since it publishes very full reports and has been under one managment from the start. The figures given below are taken from the eighth annual report, which gives data up to December 31, 1901.

Comparative yield and dividends of Homestake and Portland mines.

	Homestake mine	Portland mine.
Length of period considered	22 years 5 months	7 years 9 months.
Gross yield of ore in respective periods	$31, 190, 143	$13, 138, 525.
Dividends paid in respective periods	$8, 668, 750	$4, 027, 080.
Range in value of ore per ton	$2 to $16	$5 to $400 and upward.
Average yield per ton of ore treated during periods	$5. 48	$46.
Net yield of ore during last year of respective periods	$4. 10	$23.
Dividends to gross product	27.7 per cent	30 per cent.

These figures are of interest to those who propose to invest in mines, but of less value to the student of ore deposits in general, since they do not give the actual contents of the ore in each case, but only the amount which has been extracted. On the other hand, they do give the actual commercial results of two important and well-managed mines. The figures given for the range in value of the respective ores are somewhat arbitrary, but they are such as might be given by a conscientious promoter. Probably still higher values might fairly have been given for the Portland ores, and to the average investor these high values would present incomparably greater attractions than those furnished by the Homestake figures, which are possibly put rather high.

The actual results of many years' mining work are of comparable proportions, $46 per ton average yield for the Portland ores against not quite $5.50 for the Homestake ores, or nearly nine times as much, while the percentage of dividends to gross yield, which corresponds as nearly as possible to the percentage of profit in an ordinary business, is only 30 per cent as against $27\frac{7}{10}$ per cent, or less than 10 per cent more, for the richer ore.

It may be said that the Homestake is a free-milling ore, while the Portland ore, being a telluride, is not, and hence costs more to treat. On the other hand, the Portland mine has been running only about one-third as many years as the Homestake, and on comparing the average yield for the last year with the average yield since the inception of work, it is seen that in the Portland mine the yield has fallen off 50 per cent from the average and in the Homestake only about 25 per cent.

This is merely a practical demonstration by actual figures of what is well known by all experienced mining men—that as a purely business proposition a very large body of low-grade ore is preferable to a moderate-sized body of very rich ore.

GEOLOGICAL DESCRIPTION.

SURFACE GEOLOGY.

The town of Lead, which has a population of about 4,500, made up mainly of persons directly or indirectly dependent on the Homestake mine, occupies a basin-like valley at the head of the narrow ravine of Gold Run, down which runs the narrow-gage railroad that connects the town with the trunk line in Whitewood Valley, about 350 feet below. The rather flat-top ridges that overlook the town on the north and south are occupied by remnants of the horizontal Cambrian strata and their included sheets or sills of porphyry that have escaped erosion, while on the divide directly southeast of the town is found a body of Tertiary clays and marls containing vertebrate remains that identify it as belonging to the White River formation. Below these capping rocks, whose maximum thickness in this vicinity is about 200 feet, the valleys are entirely carved out of the Algonkian slates.

The main street of the town of Lead follows the general direction of Gold Run westward up the ravine, while subordinate streets cross it nearly at right angles. The lower or easternmost of these cross streets is approximately in the direction and position of the original outcrop of the Homestake lode. East of it, extending across the head of Gold Run Ravine, are the main offices, mills, and hoisting works of the Homestake Company. The mine openings extend up a northwest branch of the gulch, in the upper part of which, above the Star shaft, is the great open cut of the Homestake mine, while another smaller open cut lies farther eastward, back of the Homestake mill and between the Star and Old Abe shafts.

The eastern and northern walls of the Homestake open cut present a cliff section, 200 to 300 feet in height, of the mineralized slates which form the Homestake ore. In this section are seen many veins and lenses of quartz and intrusive dikes and stocks of white porphyry. These stand out in strong contrast to the dark iron-stained slates, but their outlines are much obscured by the talus slopes of broken rock which is being drawn off from the bottom of the cut and sent down through chutes to the mine below to fill the cribs that support the walls of the great ore chambers.

At the northern head of the cut the apex of the ore zone is well exposed where it passes under the Cambrian beds. The basal conglomerate of the Cambrian is here wanting, and sandy shales with some brecciated material rest directly on the Algonkian surface. The porphyry here occurs in several parallel sheets a short distance above the base of the Cambrian, and by following them eastward along the railroad track one can distinguish points where a sheet bends down to connect with a dike coming up through the Algonkian slates. Remains of a still larger sheet cap the ridge, forming small hills.

Still farther north are other open cuts, one on either side of Bobtail Gulch above the old mining hamlet of Terraville—the Deadwood-Terra cuts—and one on the south wall of Deadwood Gulch above Central—the De Smet cut. These are on the main Homestake zone, and farther east, south of Terraville, there is another cut on the Caledonia ore body.

While these cuts are not so deep as the Homestake cut, not going below the beds of the respective gulches in which they are situated, they present an even better opportunity for studying the structure of the ore-bearing slates, the contact of the overlying Cambrian beds with the Algonkian surface, and the intrusive bodies of white porphyry within these beds. On the west side of the cuts what is called the west wall of the ore body, the only one that is fairly well defined, is generally easy to distinguish. It dips eastward at approximately the same angle as the lamination of the slates, and on it the lines of pitch, which incline southward at an angle of about 23°, normal to prominent series of joint planes, are readily distinguished, as shown in the view of the Terra cut on Pl. II (p. 214). In this view also the base of the porphyry body is seen to cut across the Cambrian beds at a low angle, leaving a wedge-shaped mass between it and the Algonkian surface.

The northernmost extension of the outcrop of the Homestake lode is in Sawpit Gulch, northwest of the De Smet open cut, where are the workings of the Columbus mine. Beyond this the Homestake lode disappears under the capping of Cambrian beds in the hills to the north, but a vertical in these beds, apparently on the same line of fracture, has given rise to a deposit of siliceous ore in the latter beds.

The Columbus mine has been abandoned for some years, and its underground workings were not accessible. They are said to extend from the bed of Sawpit Gulch to Deadwood Gulch, and are opened by a 200-foot shaft in the former gulch. There are trench-like open cuts on either side of Sawpit Gulch which show rocks similar to those of the De Smet cut with abundant quartz lenses, and the mineralized ore body appears to be about 40 feet wide.

South of Lead there does not appear to have been much evidence of ore on the surface along the line of the Homestake ore zone. Nevertheless, as it was generally understood that this ore body was pitching to the southeast, a tunnel was run in from the level of Whitewood Gulch at the base of the steep face of the ridge that divides it from Lead Valley. It was intended to intersect the southern extension of the Homestake body and runs diagonally across the slates and in a direction more to the west of north than the trend of the latter. It is 2,500 feet long and said to connect with the 300-foot level of the Homestake workings, being now the property of that company. It was not accessible at time of visit, and it is not known whether it found payable ore or not.

The best surface exposures of the slates and intrusive porphyry dikes are seen between the Star shaft and the Caledonia open cut. A cross section on this general line was very carefully measured by the geologists engaged in mapping the areal geology of the region, and the result is given in fig. 4 (p. 27). The section shows ten different dikes or stocks of porphyry crossed.

ORE MINERALS.

The ores of the Homestake zone are rather ill-defined masses of rock sufficiently impregnated with gold to pay for working, but otherwise hardly to be distinguished from the country rocks in which they occur. They are singularly barren of the usual ore minerals. The gold occurs in so finely divided a state as rarely to be visible, even with a magnifying glass. Where observed, it was found in the leaf form and without evidence of crystalline structure. Besides gold, the only other metallic minerals are pyrite and arsenopyrite—the former by far the more abundant—which are irregularly disseminated through the ore, generally in very small crystals. While their presence is an a priori indication of values, they can hardly be considered as essential constituents of the ore, for they are often wanting in the relatively rich portions.

GANGUE MINERALS.

The nonmetallic or gangue mineral—quartz—is the most abundant. It occurs in veins or lens-shaped masses often of considerable size and of several different periods of formation; also in grains or crystals mostly of small size. In the crystalline form it is generally disseminated throughout the ore, and may be an original constituent of the quartzite or a later impregnation of secondary origin.

Calcite and dolomite are also common gangue minerals, generally of secondary origin, but are not universally present.

Tremolite and garnet are also of frequent occurrence in most portions of the ore body that are probably of original igneous origin, but can not be considered an essential part of the ore. Where the relative age could be determined gold is found to be of later formation than the gangue minerals.

INCLOSING ROCKS.

The Algonkian slates, in which the Homestake ore bodies occur, are schistose rocks, for the most part of sedimentary origin, one variety alone being recognized as a metamorphosed igneous rock. The latter may be classed as an amphibolite, amphibole being the most prominent constituent.

The amphibolites occur as dikes or irregular masses in the other Algonkian rocks. They are generally of greenish color, of massive and rather dense texture, with poorly developed schistosity. They are made up in general of actinolite, plagioclase, secondary quartz, and orthoclase in subordinate amount, with zoisite, ilmenite, titanite, leucoxene, and calcite as accessory minerals. The original rocks were probably basic, with pyroxene and ferromagnesian minerals as original constituents. Kernels of augite show the hornblende to be of uralitic character.

The metamorphosed sediments are quartzites, quartz-schists, mica-schists, phillites, and graphitic, garnetiferous, and chloritic slates, with intermediate varieties. A common variety of the barren slates, known among the miners as wood-yard slate from its resemblance in fracture to split firewood, is very schistose and shows wavy crenelations traversing the surfaces of schistosity. These slates consist of quartz and mica, densely aggregated, with finely divided graphite in considerable abundance in the denser varieties. In the vicinity of the ore bodies pyrite occurs as thin films on the planes of schistosity, or with quartz as the nucleus of small knot (augen)-like masses.

More recent eruptives of rather acid type cut through all these rocks, as well as indiscriminately through the ore bodies, in irregular masses, often having a dike-like form. These eruptives are of two varieties, which have been designated (1) rhyolite, (2) trachytoid phonolite.

The rhyolite-porphyry, which is by far the more common rock, is a fine-grained, granular aggregate of quartz and orthoclase with rare phenocrysts mostly altered to kaolin. The rock is very like the Leadville white porphyry in habit and composition. Small crystals of pyrite occur very abundantly, even in the freshest specimens. It cuts through the Algonkian and spreads in sheets or sills between the nearly horizontal strata of the overlying Cambrian series.

The trachytoid phonolite is a brownish-drab porphyritic rock composed of phenocrysts of salmon-colored sanidine in aphanitic groundmass. Small crystals of ægirine-augite can also be identified in the hand specimen. The microscope shows that the groundmass is made up of small rods of orthoclase, and that the rock contains a few crystals and irregular masses of identifiable nepheline, not enough, however, to bring it among the normal phonolites. This rock thus far has only been seen at the 800-foot level of the Homestake mine, though it is elsewhere known as a not uncommon rock in various parts of the northern Black Hills.[a]

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[a] More detailed petrographic descriptions of both rocks and ore minerals will be found on page 80.

The prevailing strike of the lamination planes of the slates is N. 10° to 45° W., with a dip of about 75° NE., but there are many local variations in both strike and dip, the former in places veering to the northeast. While the ore bodies are generally assumed to conform to the lamination or bedding of the slates, this is probably not strictly the case, though it was not possible to definitely prove or disprove this assumption, as both the ore bodies and the slates are rather irregular and obscured by later movements.

Where the porphyry bodies are of the dike form they show a tendency to conform to the dip and strike of the slates, but the larger bodies are very irregular in form, though an eastern dip is almost always discernible. They show a decided tendency also, like the ore bodies, to pitch to the southeast. This pitch is a structural feature that has been observed in the crystalline schists of the Appalachians and bears the same relation to the dip of the lamination planes that the pitch of the axis of an anticlinal or synclinal fold does to the dip of the sedimentary strata involved in the fold.

In the Homestake lode the pitch is best seen in strongly marked structural planes on the generally rather well-defined foot wall of the various open cuts. Its angle is 23° SE., which is also the general pitch of the ore bodies. (See Pl. II, p. 214.) There also appears to be a tendency on the part of the porphyry to conform in a general way with this pitch, but it is less susceptible of direct proof than in the case of the ore bodies themselves. The general deduction made by the writer from the above facts in their bearing upon the original mineralization of the region is as follows:

The original complex of Algonkian sediments, with its included sheets of igneous rock, was slowly compressed into anticlinal and synclinal folds, having a general northwest strike and southeast pitching axes. As the compression went on, probably with increasing intensity, these folds were squeezed into isoclines, and finally differential movement set in along planes of lamination. This movement was most marked along the general axis of the present ore body, and resulted in considerable displacement and some fracture. It had both a vertical and a lateral component, which caused a displacement vertically along the steeper sides of the fold and laterally along the axes. Irregular branching channels were thus opened, which had at the same time a steep dip to the east along the planes of lamination and a pitch to the southeast, both dip and pitch following in a general way lines of least resistance that resulted from an original tendency of the beds to slip on their dividing planes.

At present it is difficult to determine to what extent the porphyry intrusions conformed with the pitch, but it is very evident that in a general way they came up along the lamination planes, which dipped to the east. When the intrusions reached the overlying Cambrian beds they spread out in a general westerly direction, following the softer and more readily yielding members of that series.

The only movement planes that can be with certainty assigned to the post-porphyry period are breccia planes carrying fragments of porphyry and slate, that follow or are parallel to the contact of porphyry and slate.

FORM AND MANNER OF OCCURRENCE OF ORE BODIES.

The descriptions of the ore bodies which follow are necessarily imperfect for the following reasons: At the time of visit the greater portion of the upper mine workings on these ore bodies had long since been abandoned and were no longer accessible, and few persons could be found who were familiar with them at the time they were in operation. The examination of deeper workings, moreover, had not been completed when, in the autumn of 1899, the management withdrew the permission to study them which had previously been accorded to members of the Survey. Since 1899 there may have been developments in the deeper mine workings which, if known to the writer, might have modified his conclusions.

SURFACE WORKINGS.

The main Homestake body, as defined by the open cuts of the Father de Smet, Deadwood-Terra, Highland, and Homestake claims, has a trend of about N. 30° W. A second ore body, as rather imperfectly defined by the Old Abe and Caledonia open cuts, has a direction nearly north and south (N. 10° W.) and converges with the main ore body under the eastern portion of the town of Lead. The ore bodies on both these lines have a general dip to the east, as defined by their respective foot walls.

In the De Smet open cut both walls of the ore body are fairly well defined, the hanging or east wall standing nearly vertical, and the foot or west wall dipping 55° to 60° E. In the mass of slates that constitute what is left of the ore body on the south face of the cut, the original bedding can be traced by the change in color and material of the respective beds, and is seen to conform in general to the lamination or schistosity. In places, however, sharp, closely appressed folds, which are cut through by the lamination planes, can be detected in the original bedding. The folds are mostly isoclinal, sometimes, however, assuming a fan shape. Three distinct phases of quartz veins or lenses may be distinguished: (1) Material which apparently formed thin, siliceous layers in the original sedimentary material, and which has passed through the quartzite stage into a quartz that in the hand specimen can hardly be distinguished from vein quartz (see fig. 6). (2) Small seams of vein quartz which are parallel to the lamination and for the most part parallel to the bedding also, but which in the folds cut across it, as shown in Pl. III, a photograph of the crest of one of the small folds crossed by a quartz vein of this class. (3) Quartz veins or lenses are sometimes observed which cut across both lamination and bedding; these are generally larger, very irregular in shape, and appear to have been affected by differential movement within the inclosing rock mass.

No porphyry bodies are visible in the slates exposed within the open cut, but a considerable thickness of porphyry remains on the crest of the ridge above as a sheet intruded in the capping Cambrian beds. A 12-foot dike of porphyry, which strikes northeast and dips 60° to 70° NW., is cut in the tunnel which runs in from below the open cut near the bottom of Deadwood Gulch, and, following in general the strike of the ore body, connects with the 300-foot level of the Homestake workings. This is the only porphyry body observed underground in the northern part of the Homestake workings, and may have been one of the feeders of the sheet or sill in the Cambrian beds on the ridge above. The porphyry sill is not strictly parallel with the bedding, but rises gently to the west, leaving in that direction an increasing thickness of Cambrian beds between it and the Algonkian rocks. The basal conglomerate is wanting above the apex of the Homestake body, but is found in unusual thickness farther eastward toward the point of the dividing ridge between Deadwood and Bobtail gulches.

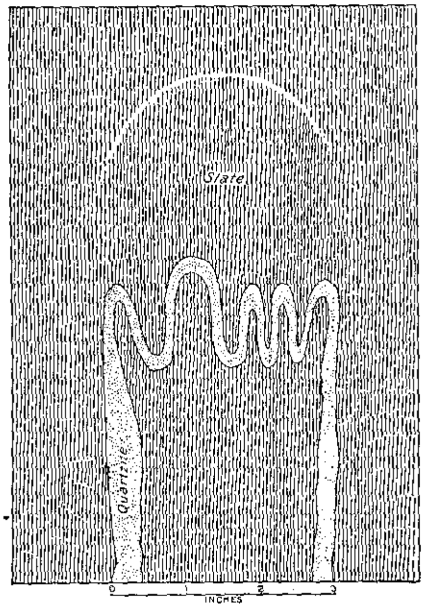

FIG. 6.—Folded and compressed quartzite band in slate.

In the Cambrian beds beneath the porphyry sill and a little to the west of the apex of the Homestake body some siliceous gold ore has been mined, which is necessarily of later formation than the original ore in the Algonkian rocks, and is probably contemporaneous with the ore bodies formed along verticals in the Terry Peak region.

In these open cuts it is impossible for the unpracticed eye to distinguish the slates which are sufficiently mineralized to constitute pay ore from those which are practically barren. Within the ore zone the rock appears to be rather more silicified and is more frequently stained by iron oxide, and there is more evidence of dynamic action. The so-called walls are apparently planes along which differential movement has taken place, especially on the foot wall. The flutings which define the direction of pitch are very evident, as shown in Pl. II (p. 214).

The form of the ore body as mined is given in the accompanying sections, which are reduced copies of those prepared by the engineers in charge of the early work[a] (fig. 7). It will be seen from these sections that not all of the material between the walls is sufficiently rich to constitute ore, as the ore body includes irregular masses which, while not absolutely barren of values, are too poor to work. Such irregular masses or horses of relatively barren material are found in all the large ore bodies of the zone and enhance the difficulty of forming a correct idea of their shape. The general form shown in these sections resembles that of the hull of a deep-keeled vessel, and the northern part of the Homestake ore zone, as well as can be determined, corresponds in general to this shape. But in the southern portion, where the present extraction is being carried on, there was, at the time of visit, no evidence of the closing together of the ore body in depth. This may have been due to the numerous porphyry bodies which have cut through and displaced it, or to the steepening of the southern pitch, which has carried the bottom far below the present workings.

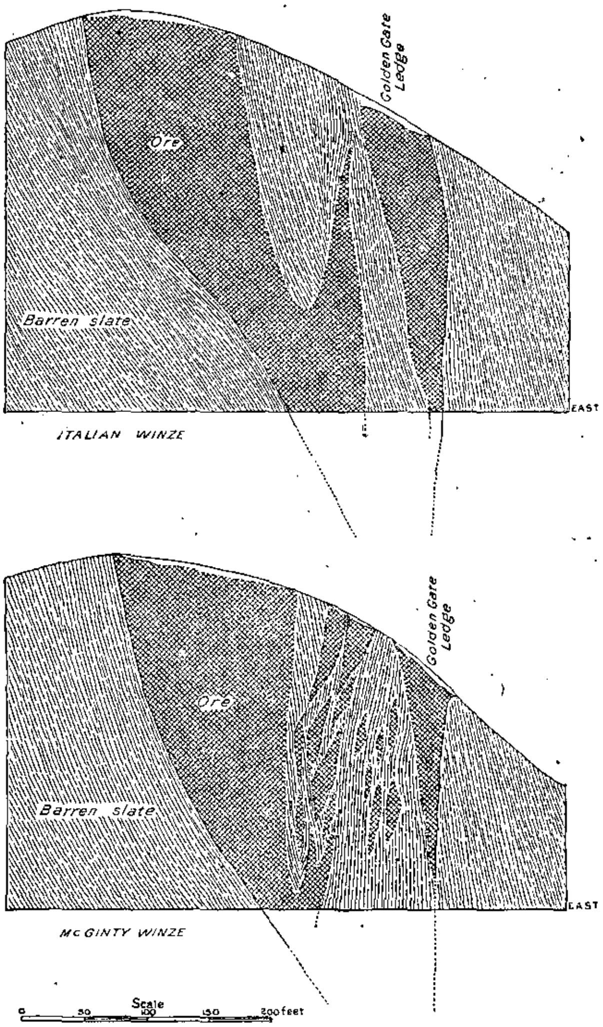

FIG. 7.—Sections of ore body, Father de Smet mine.

In the other open cuts the phenomena, as far as can be seen through the covering of talus, are essentially the same as in the De Smet. In the Homestake open cut the so-called western wall is remarkably well defined, but it does not seem to necessarily form the limit of the ore body on that side. On the ridge at the northern end of the Homestake open cut five sills or sheets of porphyry can be distinguished in

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[a] I am indebted to Mr. Richard Blackstone, engineer of the Homestake Company, for the original drawings from which these sections were copied.

the Cambrian, one of which caps the higher points of the ridge. The connection of some of these sills with dikes breaking up through the Algonkian can be more or less distinctly traced on the northeastern face of the cut. At the bottom of the lowest sill is a breccia-like material that apparently represents the flow breccia which was the forerunner of the intrusion of the sill itself.

Wherever the original outcrop of the lode can be seen under its covering of Cambrian beds the basal conglomerate appears to be wanting directly over it, but is found in unusual thickness at a little distance on either side in channel-like depressions containing abundant fragments of auriferous quartz. Hence, as is more fully explained in a later chapter, it is assumed that this outcrop was for a considerable time exposed to erosion above the waters of the gradually rising Cambrian sea.

UNDERGROUND WORKINGS.

The underground workings of the Columbus mine were inaccessible, but from accounts given by those who had seen them, it seems the ore strongly resembled that in the De Smet, and, like it, was somewhat richer than the average ore of the belt, free gold being often visible to the naked eye. In the deeper portions the ore contains considerable sulphides.

The greatest horizontal extension of ore in the Homestake mines is shown on the 300-foot level, so reckoned from the Star shaft. This level connects with the tunnel which runs in from Deadwood Gulch below the De Smet open cut, and is the only one that extends so far north, for the reason that no pay ore was found below the De Smet open cut at this level. Hence it has been assumed that the ore body has wedged out, as the form shown in the sections (fig. 7) suggests that it might. It is to be remarked that the funnel or wedge-like form shown in these sections is that which theoretically[a] might have been expected as the result of a normal faulting movement along the general axis of the Homestake body. The records show that the ore in the De Smet mine was considerably richer on the average than that in the mines farther south. This suggests that such downward leaching in the oxidized zone as took place had here been arrested in the bottom of the funnel by the converging walls and the ore was therefore relatively more enriched. In fig. 8 the general form of the ore body in horizontal section is given as far as shown by the ground actually stoped on the 300, 400, and 500-foot levels. As there shown the northernmost portion of the ore body for 1,000 to 1,500 feet is in the form of a narrow trough from 10 to 40 feet in width, which widens rapidly to the south between the Terra and Highland shafts to about 150 feet and then to 300 or 400 feet as the Star shaft is approached. In the latter portion, however, no distinct walls could be traced and considerable portions of the ore body within these limits are left standing because the ore was of too low grade. In the hanging-wall country are

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[a] Becker, G. F., Comstock lode: Mon. U. S. Geol. Survey, vol. 3, 1882, pp. 178 et seq.

many large lenses of white quartz, sometimes 10 or more feet in thickness, which, however, show no metallic minerals, though pyrite seems more abundant in the slates immediately adjoining them. The lamination of the slates in general strikes somewhat nearer north than the ore bodies, and the latter show a tendency to overlap each other en echelon, leaving barren ground between the tongues of ore.

In general in the country northwest of the Star shaft the form of the ore body fulfills fairly well the idea of a boat-shaped mass pitching to the southeast, and hence on a given horizontal section growing actually wider in that direction. With the appearance of the porphyry bodies in the vicinity of the Star shaft, however, a disturbing factor is introduced. Not only is the main ore body split up into several distinct parts by the intrusion of the porphyry sheets, but there are separate detached ore bodies or chimneys whose structural dependence on each other could not be determined from the examination made. These bodies lie south of the Star shaft, the principal ones, going eastward, being the Independence body near the

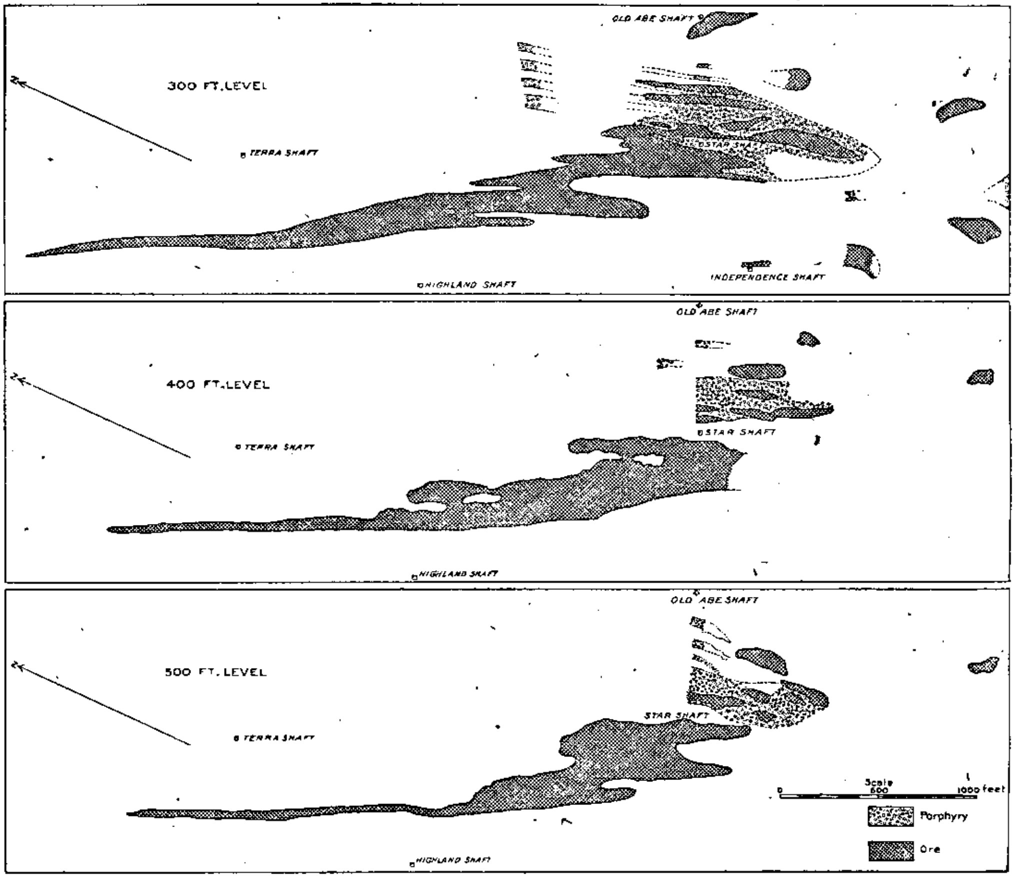

FIG. 8.—Plans of Homestake ore bodies on the 300, 400, and 500 foot levels.

shaft of that name, the Pierce stope, the East stope, the Lincoln, and the Amicus body, the latter near the Old Abe shaft. The main working shaft at time of visit was the Star shaft, from which levels are opened at 100-foot intervals and drifts run out to cut the ore bodies that were worked in the next level above. The system of mining pursued involves the opening of large chambers in the ore zone, rapid extraction of the pay ore, and prompt filling up of the stopes with waste, so that no detailed study of the individual bodies was practicable. The most important data were furnished by the drifts which are run on each level eastward from the Star shaft to the Old Abe or Pump shaft. These have been used as the common ordinates for the successive mine plans given in fig. 8, and from them a cross section of the different porphyry sheets that intersect the main ore body has been constructed, which is reproduced in fig. 9. Although based on accurately determined data at each level the representation of the form of the bodies is necessarily somewhat diagrammatic, for it is not possible to trace their outlines between the levels. Nevertheless, from this section, combined with other data partly shown on the horizontal sections, it is evident that the porphyry bodies have a fairly uniform dip

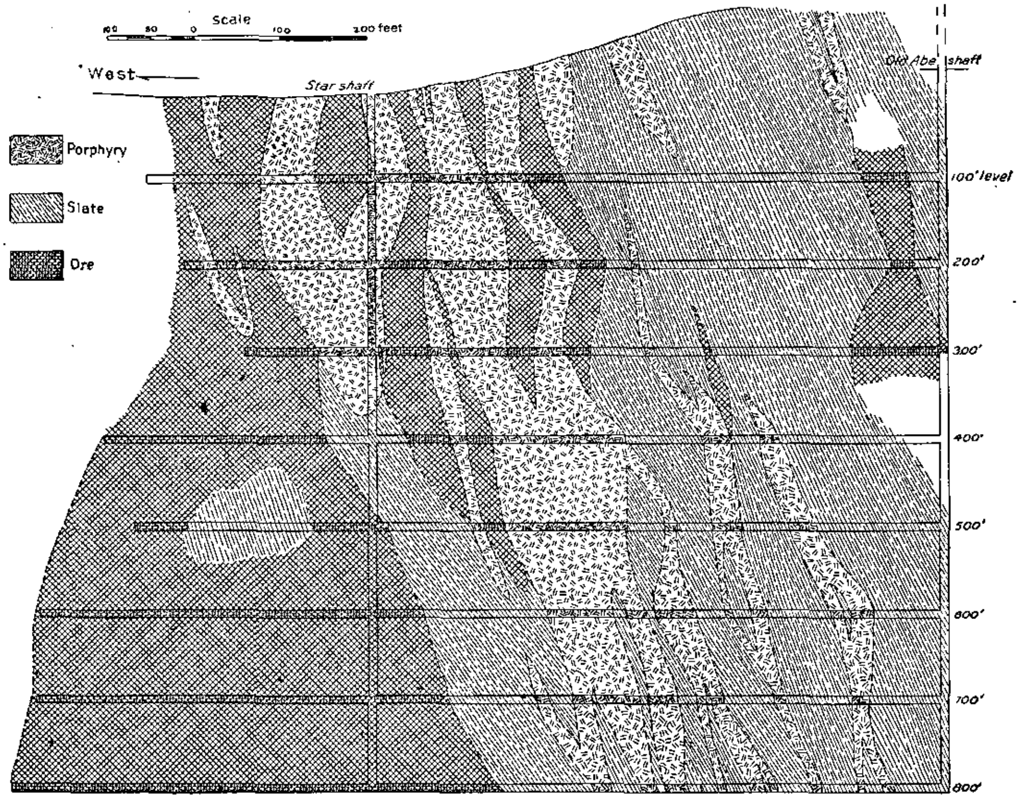

FIG. 9.—Star-Old Abe section of porphyry and ore bodies.

to the east in general accordance with, though somewhat steeper, than the lamination of the slates. Furthermore, it is seen that they pitch to the southeast as do the ore bodies, and, finally, that they tend to spread out more and occupy a wider horizontal section as they approach the surface. It is probably due to their southern pitch that many of these ore bodies appear to wedge out in depth, and if a parallel section could be made on a plane somewhat farther south it would probably be found that the point of the wedge is successively deeper in each section. The only other cross section of the porphyry dikes observed was in a cross-cut drift on the 300-foot level running from the north header or drift of the Star shaft eastward about 900 feet to the Caledonia workings. This drift cuts six dike-like bodies of porphyry from 12 to 70 feet in thickness and with an aggregate thickness of about 200 feet. Comparing this cross section with the eight sections obtained in the Star-Old Abe drifts, it is seen that while each differs somewhat in the number and thickness of individual dikes the aggregate thickness of all of them cut on these various lines presents a rather remarkable uniformity, ranging only between the extreme limits of 150 and 225 feet and averaging about 200 feet. The dikes may, therefore, be regarded as representing a single intrusion of porphyry, which had been forced between the lamination of the slates and cut across the eastern edge of the ore body, entirely inclosing in some cases large masses of ore-bearing ground. A most interesting and instructive feature of the dikes is the frequent occurrence at their contact with the slates of a line of breccia, generally conforming with the plane of contact, but sometimes branching off into the body of the slates. While some of these breccia seams may be, as Doctor Jaggar suggests, flow breccias or broken material which was pushed ahead of the magma at the time of its first intrusion, they are, for the most part, true friction breccias and contain broken fragments of the porphyry, as well as of slates. In one case a seam of brecciated slate and porphyry fragments was found in the slates at a distance of 15 feet from the porphyry contact. The breccias thus indicate clearly that there have been dynamic movements within the mass of slate and porphyry since the intrusion and consolidation of the latter. They are found generally on but one side of the dike, but in a few cases were observed at either contact. A study of these friction breccias show that mineralizing solutions must have entered along the channels produced by these movements. Panning tests prove that the breccias contain gold values, though generally less than the adjoining slates, while the porphyry on the opposite wall is generally found to be practically barren of gold. On the other hand, both breccia and adjoining slates are abundantly impregnated with pyrite, as is the porphyry to a less degree for a short distance from the contact. There has also been a certain amount of silicification accompanying this later mineralizing action. Not only the breccias and slates but also the porphyry itself have been silicified in the neighborhood of these secondary fractures, and some of the large quartz lenses in the hanging-wall portion of the body are apparently of more recent origin than the porphyry.

On the 800-foot level, a little south of the Star shaft, the mine drifts have disclosed the top of a body of phonolite which crosses the lamination of the slates in a northeasterly direction. As seen at time of visit, it consisted of two detached masses with the same general strike on their northern contacts. These masses are probably projecting knobs of the upper surface of a single body, and may be expected to join below. They are presumably of later origin than the rhyolite-porphyry. Whether they have had any influence on ore deposition is not known.

CALEDONIA ORE BODY.

This ore body was only observed on the 300 and 600 foot levels. It lies entirely to the east of the porphyry intrusion which is cut by the other mine workings, and the porphyry body seen at the surface near the open cut did not appear in the lower workings of this mine. A narrow dike of porphyry striking N. 10° W. is, however, cut by the somewhat curving drift which reaches the Caledonia workings from the Old Abe shaft on the 600-foot level. The slates in this portion of the workings have the same general strike, namely, a little west of north, though it locally bends a little to the east of north. Their dip is about 45° E., apparently somewhat less steep than that of the porphyry. The ore body has the usual eastern dip, which also seems to be rather steeper than that of the slates. The inclosing rocks are amphibolitic and abundantly impregnated with pyrite.

CONCLUSIONS.

From the observations made in the underground workings, of which only a bald statement of the most important has been given above, the following conclusions have been drawn as to the form and probable origin of these ore bodies. The determining cause of the original ore deposition would appear to have been a compression and crushing of the rocks along two converging lines, a line of major crushing, trending about N. 30° W., and a line of minor movement, running about N. 10° W. and crossing the line of major crushing just south of the Star shaft, where now are opened the shafts and most extensive ore bodies. The movement which produced this crushing must have been very gradual and of a nature similar to that which produced the lamination of the slates. It resulted not in large definite fractures or in brecciation of the rock, as in vein fissures or crushed zones, where ore generally accumulates, but in a differential movement along the already determined planes of lamination and pitch, the effects of which, however, extended through zones or belts that were somewhat more steeply inclined than either of these structures, especially at the junction of the lines of major and minor crushing, where the resultant crushed zone seems to have a nearly vertical direction.

Jaggar has suggested that the general zone of crushing is nearly coincident with the change of dip of the lamination of the slates, but no facts bearing directly upon this theory were observed in the underground workings. If, however, a strong line of folding had been developed in the original sedimentary series prior to the compression which produced the lamination, it is very probable that during the compression the limbs of the folds would have been lines of weakness along which the strain might have resulted in some differential movement and special crushing and dynamo-metamorphism of the rocks. Along these lines of movement the solutions rose from which were precipitated the original deposits of iron sulphides and gold. There is no definite evidence as to the source of these metals. The presence of garnet-amphibole rocks is suggestive of contact metamorphism, but neither magnetite nor specular iron, which are usually characteristic of contact mineralization, is found with the ore, nor in its distribution was the ore observed to have any special relation to the older intrusive bodies. The ore is distinctly of later formation than the garnet and associated minerals, and the latter are seen by microscopic study to have been formed since the dynamic action which produced lamination or schistosity in the rocks. The metals may be assumed, therefore, to have been derived from the leaching of rocks at some distance below the surface by percolating waters, and to have been precipitated in contact with the graphitic matter, and possibly also with original pyrite, present in the slates.

The second mineralization which came after the later intrusion of rhyolite-porphyry evidently followed the same general channels and consisted essentially of the same materials, iron sulphide, and gold. It did not stop at the Cambrian contact, however, but continued on through cracks or fissures into the Cambrian rocks and deposited abundant auriferous pyrite in the basal conglomerate adjoining and in the calcareous beds immediately overlying the outcrop of the Homestake belt. The most important difference as yet noted between the two periods of deposition is the local formation in the conglomerates of tungstate of iron which seems to replace the sulphide. In these later deposits no evidence of pneumatolytic action has been observed. As to whether mineralization went on during the period between the pre-Cambrian and Tertiary deposition, there is also no evidence.

The deposits in general are remarkable for their freedom from metals other than those already mentioned. There is said to be 0.11 ounce of silver per ton in the ores and not over 0.05 per cent of copper in the concentrates. Secondary enrichment of the ores by surface leaching has also been of relatively small importance. Some of the surface ores of the Homestake body are said to have assayed as high as $16 per ton, and the ore taken from De Smet and Columbus mines is said to have averaged about $1 per ton richer than the ores of the more southern mines. It is said that the concentrates in the upper workings of the Homestake mine, where the ore was almost completely oxidized, carried only about $1 in gold per ton, but as oxidation has decreased in depth the amount of gold in the concentrates has increased until in the lower levels, where oxidation has not penetrated, the concentrates carry $8 in gold per ton, while the ore taken as a whole averages $5.50. Under these conditions there is no evidence of any decrease in the values with depth, while the size of the ore body appears to be increasing rather than decreasing. On the other hand, it would appear from such evidence as was obtained during this examination that the pitch of ore is not as regular as seemed to be the case in the upper and northern portion of the workings, but that at present it has steepened so as to nearly approach the vertical, while the eastern dip has also steepened. This might have been expected if, as suggested above, the present result is dependent on the converging or crossing of movement on two distinct lines.

PETROGRAPHIC STUDY OF THE HOMESTAKE ORES.

By J. D. Irving.

The ores of the Homestake mine occur in the rocks of the Algonkian, which consist of a varied series of highly altered and, in most cases, crystalline rocks. They may be divided into two groups—metamorphosed sediments, and metamorphosed igneous rocks.

METAMORPHOSED SEDIMENTS.

The rocks of this group constitute by far the greater portion of the Algonkian series. They are quartzites, quartz-schists, mica-schists, phyllites, graphitic slates and schists, chloritic slates and schists, and many varieties intermediate in position.

METAMORPHOSED IGNEOUS ROCKS.

Under this head are placed a series of varyingly schistose rocks of uniformly basic character. They are here grouped together under the comprehensive term "amphibolite," as amphibole is the most noticeable constituent. As a whole they present a greenish appearance, a massive and rather dense texture, and in the majority of cases possess a schistosity but poorly developed. They occur as dikes or irregular masses in the other Algonkian rocks, and in many cases show a massive core with the schistosity increasing toward the periphery. Mineralogically they consist of pale-greenish amphibole (usually actinolite) with some original plagioclase, secondary quartz, and orthoclase in subordinate amount, with accessory zoisite, ilmenite, titanite, leucoxene, and calcite. Original kernels of augite show the hornblende and actinolite to be of a uralitic character. Some of the more highly metamorphosed rocks show a development of biotite.

In texture the metamorphosed igneous rocks vary from a fine-grained dense rock, though diabasic, to one very coarse with a characteristic mottled appearance resembling the skin of a leopard. The coarsest specimens possess a texture and general appearance suggestive of gabbros, pyroxenites, and other plutonic rocks of basic character. In the less extensive and dike-like occurrences the vestiges of an original diabasic texture are often well defined. There seems little reason to doubt that the amphibolite group as here exposed is referable to an original series of basic rocks whose chief mineral was pyroxene.

RELATION OF THE ORES TO THE ALGONKIAN ROCKS.

The ores of the Homestake mine, taken as a whole, can not be said to present any constant features that will serve to distinguish them from the characteristic but barren rocks of the Algonkian.

Pyrite is by far the most invariable indication of mineralization, but is notably absent from many of the richest portions of the ore. Quartz, dolomite, calcite, and arsenopyrite are also of frequent occurrence and sometimes constitute the main body of the ore, but no decrease in values can be noticed when they are absent. Again, garnet and tremolite will be present in so great abundance as to constitute the larger portion of the gangue mineral, but bodies of ore will occur at no appreciable distance in which no trace of these minerals can be observed. Thus, it will appear that although we find pyrite, quartz, dolomite, calcite, arsenopyrite, tremolite, and garnet frequently constituting either separately or in combination the gangue of the ore, no one of these minerals can be stated to be a sine qua non to the occurrence of the gold. In general, however, it may be said that, compared with the barren areas of the same formation, the ores occupy a zone which presents a greater number of secondary minerals; a more constant occurrence of sulphides, dolomite, quartz, calcite, and arsenopyrite; and, finally, a more advanced degree of contortion and distortion.

DETAILED DESCRIPTION.

WALL ROCK.

In the set of collected rocks were two specimens of that variety of wall rock known among the miners as "woodyard" slates. These were taken from the north end of the 300-foot level in the long crosscut.

One specimen (No. 45) is an extremely fine-grained, evenly schistose rock of a blackish-gray color. It splits more easily along those planes which show an abundant development of extremely fine mica, to the arrangement of which in parallel plates the schistosity is due. Cross jointing frequently occurs, and the rock generally shows wavy crenelations traversing the surface of schistosity. Thin films of pyrite occur here and there in the secondary planes and the same mineral may occasionally be observed in small isolated masses. The microscope shows this rock to be a dense aggregate of quartz, mica, and a very finely divided dull-black material, which is presumably graphite. This graphitic material occurs in such abundance as to make microscopic sections very opaque. Occasional lenses of small size occur in which irregular masses of pyrites and quartz may be observed.

The coarser variety of the so-called "woodyard" slates (No. 44) shows lighter-colored, rather larger flakes of mica, and a more marked evidence of crumpling. It contains considerable chlorite, and between the micaceous layers are intercalated bands of a more quartzose character. The quartz grains are small and show considerable recementation. The mica is muscovite. The light color of the rock is due to the absence of the graphitic constituent. Considered as a whole, these specimens show a less disturbed condition than the ores; they contain far less pyrite and are much more evenly schistose.

ORES.

In the set of specimens collected the following three varieties of ore can be distinguished: (1) Banded ore; that is, ore wherein the mineralization has not been accompanied by distortion of the original structures of the rock. (2) Contorted ore; that is, ore where the original rock has undergone very great distortion. This distortion has generally been accompanied by the introduction of numerous minerals not an essential part of the Algonkian series. (3) Massive ore; that is, ore where few, if any, traces of either the original structure or the original ingredients in the Algonkian rock can be observed. These three varieties are separated from one another by no sharp lines of demarcation, but transitional varieties occur showing all stages of distortion and mineralization.

BANDED ORE.

A specimen of ore taken from the middle breast of the 800-foot level shows complete preservation of the original structures and characteristics of the Algonkian rock after mineralization. It is a black, schistose rock (specimens 4 and 5) in which the original sedimentary banding is very pronounced. The bands are caused by the alternation of narrow and exceedingly dense layers of a slaty aspect with broader bands of coarse texture and slightly lighter color. The narrow bands have a slaty cleavage at a considerable angle to the bedding. The microscope shows them to be composed of irregular blades of biotite parallel to the cleavage and a confused aggregate of very finely divided black material of presumably graphitic character. Small grains of quartz and orthoclase occur together with the biotite. Along the planes of schistosity in these dark bands occur broad and extremely thin films of pyrite.

The coarser layers are composed of irregularly bounded grains of orthoclase of considerable size and irregular patches of biotite. The orthoclase grains contain many inclusions and have originated from the metamorphism of the primary ingredients of the rock. The biotite is interstitial between the orthoclase individuals and is in very irregularly bounded patches arranged without any special orientation. They are generally of sufficient size to be identified in the hand specimen. It is interesting to note that the graphitic material in the body of the orthoclase is arranged in very narrow bands of alternately darker and lighter color according to the greater or less abundance of the graphite (see fig. 10, 1). These bands follow the original bedding planes of the rock, causing the contrast in color which makes the banding prominent. The schistosity has fractured them so that their continuity is interrupted by a succession of small displacements (see fig. 10, 2). Joint planes can be frequently observed running in directions at various angles to the prevailing schistosity. In some of these seams carbonates—probably calcite and dolomite—occur; in others, pyrite.

A slightly more oxidized variety of banded ore is seen in specimen No. 25 from the north end of the 400-foot level near the De Smet. It is a blackish-gray rock with a pronounced sedimentary banding and poorly developed schistosity. Small crystals of arsenopyrite and pyrite are scattered sparsely through it with no semblance of regularity. The pyrite occurs also in irregularly distributed masses or in thin films. There is later deposition of pyrite, together with considerable limonite, along secondary fractures. Viewed under the microscope the rock is seen to consist of biotite, quartz in grains, and numerous lenticular masses or crystals of pyrite and arsenopyrite. The specimen has suffered little or no deformation, and but for the occurrence of the sulphides presents no noticeable features which would serve to characterize it as an ore.

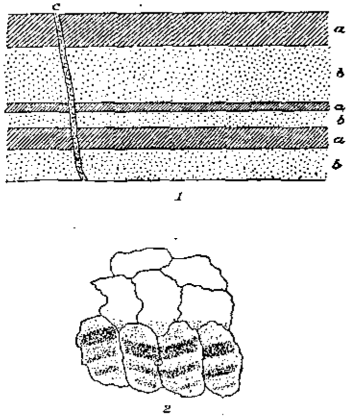

FIG. 10.—Banding of Algonkian slate due to parallel arrangement of graphitic material.

Nos. 15 and 16, taken from the north end of the 400-foot level, show still another variety of banded ore. In No. 15 the sedimentary banding is scarcely noticeable and the rock closely resembles the "woodyard" slates in its general appearance. It is a fine-grained grayish phyllite, with bands of somewhat more graphitic character occurring without regularity. Pyrite is present in very thin films along the planes of schistosity.

No. 16 is a rock of very similar character, but exhibits two directions of schistosity. The first, or that parallel to the original banding, causes the rock to break into broad flat slabs. The second is at an angle to this and exists only between the first described. The microscope shows the rock to be composed of quartz grains, fine blades of muscovite, biotite, and chlorite, together with considerable calcite in irregular patches and some pyrite.

No. 24 shows still a different variety of banded ore. It is from the Lincoln stope on the 400-foot level. It is a dense rock composed of alternating light and dark bands. The dark bands have a black slaty appearance and show numerous small flakes of biotite, together with minute crystals and masses of mispickel and pyrite. The lighter bands are of an extremely fine quartzite, somewhat friable in character, and colored light green from contained chlorite. The whole specimen is cut by a cross vein of quartz and pyrite which shows a distinct vein structure and is almost perpendicular to the schistosity. The quartz of this vein is of glassy character and the pyrite occurs chiefly in the center, filling the space between two quartz masses on the sides. The section shows only a limited portion of the specimen and is taken from the light-green band. This consists of fine grains of quartz, showing considerable recementation, some interstitial calcite, and very numerous extremely thin shredded flakes of chlorite. A few isolated patches of titanite may also be observed.

No. 8, from the south breast of the 700-foot level, is a dark-green schistose rock, shot through with fine lenticular masses of pyrite, whose longer diameters are in the direction of lamination. Fibrous tremolite can also be observed in small radiating bundles. The microscope shows the rock to be a laminated aggregate of quartz grains, tremolite, chlorite, and lenticular masses of pyrite; a little biotite was also observed.

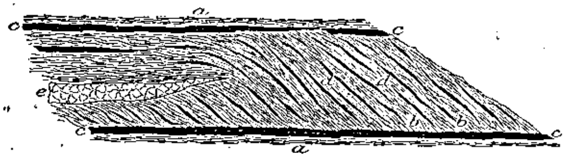

FIG. 11.—Direction of schistosity in mineralized schists.

Specimen No. 6, from the middle west shoot on the 800-foot level, shows a transition from that ore which preserves the original Algonkian structure to ore of a more contorted character. It is a markedly schistose rock consisting of granular quartzite, glassy quartz, and heavy bands of iron sulphide mingled together in a confused manner. The sulphide is of a slightly pinkish tinge and may be pyrrhotite. Intimately mixed with the quartz is considerable dolomite showing curved faces and sometimes a slightly yellowish color. Under the microscope the sulphides show shattering, biotite, quartz, and calcite occurring between the fragments. In the portion which consists mainly of quartzite the grains are noticeably recemented. In the micaceous portion, green amphibole, chlorite, biotite, and a little titanite occur. All of the minerals show strain phenomena, and the entire specimen is distorted, so that the relations of the various layers are very confused.

Specimen No. 30, from the west stope on the 500-foot level, is a dense granular quartzite heavily impregnated with pyrite, crystals of arsenopyrite, and carbonates. Traces of a laminated texture are observable in the parallel alignment of biotite and other micas which occur in a narrow band. The greenish color is due to thin microscopic blades of chlorite. Under the microscope the separate grains of quartz show recementation. There is present considerable biotite and pyrite in irregular masses, arsenopyrite always in characteristic crystals, and some calcite.

No. 3 is a fine-grained compact quartzite, colored dark green by extremely minute microscopic blades of chlorite and containing scattered bunches of radially arranged tremolite needles. The microscope shows the rock to be made up of an aggregate of small quartz grains, all showing secondary enlargement, scattered masses of titanite, and a little calcite. All of the original quartz grains show indications of heavy strains.

CONTORTED ORE.

The term "contorted" ore has been used to designate that variety of ore in which the original schistose character of the Algonkian has been greatly distorted, and in which minerals not commonly forming an essential part of the Algonkian rocks have been introduced in greater or less abundance.

Specimens Nos. 32 and 934 illustrate this variety of ore. They are extremely fine-grained, chloritic schists, with satin-like luster, distorted and gnarled so as to resemble the texture of knotted wood. Lenticular masses and augen of dolomite, calcite, and quartz intimately mixed together, or of glassy quartz, pyrite, and mispickel are abundant; radiating masses of tremolite occur sparingly. Where the distortion has not gone so far that no definite structure can be recognized, the knots or augen are beautifully developed. A blow with the hammer will generally reveal the presence of a kernel of arsenopyrite or pyrite, to which the knots owe their origin. These kernels of sulphide are often one-half or three-fourths of an inch in diameter. They are generally well crystallized, and the schist passes up over them in very even curves. In other instances the distortion has gone so far (e. g., specimen No. 26) that the original structure of the schist has been completely obliterated, and masses of quartz, sulphides, chlorite, tremolite, dolomite, and calcite occur together in very confused relations.

In specimen No. 26 a very large and irregular mass of quartz may be seen embedded in the chlorite. The arsenopyrite is almost always in distinct crystals, or groups of crystals, and the pyrite is sometimes in crystals, but more frequently in large irregular masses. In many instances pyrite and arsenopyrite are mingled together in a single mass, each mineral being recognizable by its characteristic color, but neither showing any definite relation to the other. Occasional patches of garnet may be seen in the chlorite, but they are rather sparingly developed. The microscope shows the greenish portion to be composed mainly of chlorite, with some few needles of actinolite or hornblende, of which the chlorite seems to be the alteration product. The crystals of arsenopyrite are frequently slightly shattered and their interstices filled with quartz, but the fragments are never very distant from one another, and it is probable that the movement which produced the shattering was very slight.

In a section of specimen No. 32 secondary veins of calcite can be observed cutting directly across chlorite, sulphides, and quartz indiscriminately. This shows that there has been an introduction of calcite subsequent to all of the early mineralization.

In one specimen of this chloritic ore (No. 896) a considerable development of free gold was observed. This gold occurs in two distinct relations to the gangue minerals; first, contained in the quartz in extremely thin leaves following apparent fracture lines; second, contained completely in the chlorite-schist. In some instances the gold leaves in the quartz extend up into the chlorite of the main mass. In neither case is the gold associated with sulphides, but small fragments of quartz, some of them completely surrounded by gold, occur with all of those masses of gold in the chloritic portion of the ore. A specimen of the gold in the chlorite was seen in the mine inspector's office in which a leaf of gold about one-half inch in breadth and one sixty-fourth of an inch in thickness projects from the chlorite and curves over on the outside of the rock. In one instance a leaf of gold extends from the quartz into the chlorite by which the latter was surrounded and occurs there together with chlorite, filling the interstices between irregular grains of quartz. Most of this gold is in exceedingly thin leaves, none of it ever showing nugget-like appearance. A distinct crystalline structure could not be observed in any of the gold, but its manner of reflecting light suggested the presence of minute crystalline faces.

MASSIVE ORE.

Under the name of "massive" ore has been placed that variety of ore in which all structures—both of banding and schistosity, which characterize the Algonkian rock—have been completely obliterated. This variety of ore consists chiefly of minerals which have been introduced either by deposition in spaces left between Algonkian rocks or by replacement. Such minerals as are characteristic of the metamorphosed Algonkian occur either in this ore as broken fragments or in the Algonkian rock which forms the walls of the cavities in which the ore was found. One of the most interesting varieties of this ore is that composed of dolomite and quartz. A characteristic specimen of this variety of ore (No. 925) was taken from the south breast on the 800-foot level. It consists of a large irregular mass of coarsely crystalline dolomite confusedly mingled with chlorite, tremolite, irregular masses of glassy quartz, and some pyrite. The main dolomite mass is intersected by joint planes filled with glassy quartz and evidently of a much later age than the rest of the ore. The microscope shows the dolomite to be made up of a great number of separate individuals, none of them with crystalline boundaries, but impinging upon one another in very irregular lines. They show very great dynamic stress in their wavy extinction and distorted cleavage. A few identifiable masses of calcite occur with the dolomite. The quartz which fills the joint planes is seen to be composed of many small individuals, but is very clear and shows no indication of strain.

Another variety of massive ore is seen in that taken from the west shoot on the 800-foot level (specimen 7). It is composed of a confused aggregate of radiating tremolite of a brownish-green color in hand specimens but almost colorless by transmitted light, biotite, quartz grains, dolomite, and chlorite. Tremolite is the most noticeable mineral in the ore. Under the microscope the quartz grains and dolomite are seen to be mingled together in a confused manner, neither ingredient exhibiting crystalline boundaries. Isolated grains of titanite, ragged flakes of biotite, a little green hornblende, and some quartz are also present. A most interesting variety of massive ore is that occurring in the Pierce stope and known as "garnetiferous" ore (No. 18, No. 19, and No. 20). It is a confused grayish mass of tremolite, glassy and granular quartz, dolomite, pyrite, arsenopyrite, and garnet. The microscope shows garnet, chlorite, dolomite, quartz, pyrite, and arsenopyrite. The garnet is very largely broken and shattered, especially so when occurring in the quartz and dolomite. Those masses which are entirely contained in the tremolite are less shattered. As a whole it is very much broken and is often partially altered to chlorite and a green, pleochroic hydromica, perhaps related to ripidolite. The garnet fragments are surrounded and invaded along fracture lines by dolomite, quartz, and pyrite, showing that these three minerals were formed later than the garnet, which is itself probably the product of metamorphic action. In some cases the garnet has gone so far in alteration that only a green confused mass of chlorite and hydromica remains, with perhaps a kernel or two of garnet to indicate its origin. Fragments of garnet occur completely isolated from the parent mass and surrounded by quartz. The quartz consists of an aggregate of irregular grains whose boundaries have been recemented in many cases. The granular aspect is probably due in large measure to shattering, of which the heavy strain phenomena are an additional evidence. Pyrite grains occur scattered through the quartz. The dolomite, when seen in a hand specimen, presents many curved faces and under the microscope shows wavy extinction due to dynamic stress. It has never developed the twinning planes parallel to $-\frac{1}{2}$ R. which are so characteristic of strained calcite. It is broken so that large fragments are often isolated and imbedded in a quartz matrix, the separate faces being eaten into at times by the quartz. This phenomenon of quartz occurring later than the dolomite is again seen on the 800-foot level, where a large mass of dolomitic ore is cut by small stringers of glassy quartz rarely more than one-sixteenth of an inch in width, but distinctly filling joint planes in the dolomite (No. 925).

Specimen No. 19 shows large and distinct cubes of pyrite embedded partly in one of the ingredients of the ore and partly in another. The arsenopyrite is present in small crystals of characteristic shape, but is not so prominent in the garnetiferous portions as in the rest of the ore. The dolomite in Specimen No. 19 is slightly yellowish in color and probably has some of the siderite molecule in its composition. The tremolite sometimes penetrates the garnet and in some cases has been replaced by calcite. The dolomite of the main ore mass is to be sharply distinguished from a few later calcite seams which cut both quartz and garnet indiscriminately. The quartz frequently contains little porous and fluidal inclusions arranged in lines at varying angles to one another. In this variety of garnetiferous ore, therefore, is seen the following sequence of events:

(1) The metamorphic action which produced the tremolite and the garnets. (2) The shattering of the original rock which gave rise to the broken condition of the garnets. (3) The introduction of the dolomite between the fragments of the garnet. (4) The shattering of the rock as then formed and the introduction of the quartz into the spaces thus left vacant. These relations will be well illustrated by Pls. VII, *A* and *B*.

It is probable that most of the pyrite was introduced at the same time as the quartz, but, except to say that it is later than the garnet, no definite evidence as to its age is available. Later than all these events occurred considerable movement and crushing which produced strain phenomena in the quartz and the subsequent recementation of the shattered individuals by quartz.

PORPHYRIES.

The eruptive rocks occurring in the Homestake mine are rhyolite and trachytoid phonolite.

The rhyolite, which is by far the most abundant of the two, is a dense, almost aphanitic, grayish-white rock resembling novaculite. Under the microscope it shows an extremely fine aggregate of low polarizing individuals in granular arrangement. None of them are large enough to be accurately determined, but they are probably quartz and orthoclase. Phenocrysts are scattered very sparsely through the rock and are uniformly small in size and show very advanced stages of alteration. In the very numerous sections examined all of the phenocrysts were either completely kaolinized or weathered and the spaces filled by secondary calcite. The only basic mineral present is pyrite, which occurs abundantly even in the freshest specimens. It generally shows small dodecahedra or pyritohedra, or is in irregular rounded masses of no definite form. These crystals and masses are generally extremely small, so that they appear in hand specimens merely as minute, glistening specks. No dark silicates of any kind can be seen in the slides. There is a general resemblance of this rock to the rhyolite or white porphyry which occurs in the vicinity of Leadville and elsewhere.

A second variety of porphyry is a rock belonging to the phonolite family. It is a porphyritic rock exhibiting a dense, brownish-green, almost aphanitic groundmass, in which are embedded glassy or salmon-colored crystals of sanidine. Small crystals of aegirine-augite can also be identified in the hand specimen. The microscope shows the groundmass to be made up of small rods of orthoclase arranged in flow structure, together with innumerable shredded masses of aegirine. A few crystals and irregular masses of identifiable nepheline occur. The large aegirine-augites are generally well bounded and show the characteristic cleavage and optical characters of this variety of pyroxene. The rock has scarcely sufficient nepheline to be classed as a phonolite, and yet the proportion of that mineral is too large and the amount of soda pyroxene is too great to allow its classification with the soda trachytes. It is distinctly a transitional type and belongs to that variety of rocks which is very common in the northern Black Hills and has been classified as "trachytoid phonolites."

PORPHYRY BRECCIA.

On the border of many of the dikes of rhyolite occur varying widths of brecciated material consisting of angular fragments of porphyry, ore, and distorted schist. On the upper levels these breccias are too much oxidized to afford any satisfactory evidence from their study. Those from the lower levels, however, present some interesting features.

No. 78 occurs on the contact of the dike with barren slates. It consists of sharply angular fragments of porphyry, glassy quartz, and dolomite embedded in a matrix of black comminuted schist of a very graphitic character and more or less heavily impregnated with pyrite.

No. 29, taken from the east stope on the 500-foot level, shows a grayish mass of brecciated material containing much fine-grained pyrite and small angular masses of porphyry. In this are embedded large and small more or less broken angular fragments of glassy quartz. Pyrite occurs in the quartz rather more sparingly than in the interstitial material. The latter is an extremely fine, black, graphitic aggregate, which, by reason of its very yielding character, has been thrust into the minutest crevices. The pyrite occurs most abundantly in this matrix.

Specimen No. 31 shows fragments of porphyry completely embedded in glassy quartz and pyrite of the ore mass. The quartz fragments are made up of many separate individuals with very irregular boundaries, and in polarized light give evidence of great dynamic stress. Much calcite has been introduced between the fragments of quartz and also occurs in irregular patches in the breccia matrix. It is worthy of note that the pyrite in the matrix, even where present in distinct crystals and large masses, shows no evidence of shattering. It is therefore probable that this mineral was introduced either subsequent to or contemporaneous with the brecciation.

Specimen No. 47 is a breccia showing a more advanced degree of comminution. Under the microscope we are able to detect fragments of quartz, angular fragments of porphyry, and irregular pieces of quartzite and schist. In the interstices between these different fragments is a matrix composed of black crushed material of graphitic character. Some calcite and a little clay resulting from a decomposition of the feldspar are also present. The quartz shows the usual strain phenomena. The softer material in this case, as in the other specimens of breccia, has suffered the greatest deformation and has been introduced between the harder fragments without destroying their angularity.

SUMMARY.

Although a careful study of the collected specimens from the Homestake mine does not lead to any very positive conclusions, it is possible to get from the relationships of the different minerals some evidence as to the general nature and origin of the mineralization. The ores occur along a definite zone which follows roughly the general trend of the schistosity of the Algonkian series. This zone has been the line along which successive periods of differential movement and fracturing have occurred. That these periods of movement were subsequent to metamorphic action is proved—first, by the partial or complete obliteration of metamorphic structures in much of the Homestake ore, and, second, by the shattering of many of the minerals which are the characteristic products of metamorphic action. Thus, for instance, the gnarled and knotted structures of the chlorite-schists from the Pierce stope; the departure of the schistosity from the even and regular direction so characteristic of "woodyard" slates to one wholly without regularity; the occurrence of various foreign minerals in distorted and confused relations; and, finally, the complete obliteration of all metamorphic structures in some of the more massive varieties of ore must be assigned to disturbances which have occurred long after metamorphic agencies had ceased to operate.

For the better understanding of the relations of the different ingredients of the ores and the conclusions which may be drawn from their study the following general summary is introduced. The minerals of which the ores are composed fall into the following three well-defined groups: (1) Minerals which are an essential part of the Algonkian rocks, either as original ingredients of the series prior to metamorphic action or as products of regional metamorphism. These include quartz, orthoclase, hornblende, biotite, garnet, tremolite, actinolite, titanite, and graphite. (2) Minerals that are the result of mineralization as distinguished from metamorphism, pyrite, arsenopyrite, quartz, dolomite, calcite, and gold. (3) Minerals that are the result of the oxidizing and decomposing action of surface waters, iron oxide, and calcite. The minerals of this group, except in so far as it is necessary to distinguish them from the others, are unimportant.

It is readily seen that quartz occurs as the most abundant and characteristic mineral in both series, nor have we, except in its structural relations, any means of determining to which class it belongs. It occurs in three forms: 1. As a relic of the quartz of the original rock prior to metamorphism, in which case it may generally be distinguished by its occurrence in somewhat stretched grains which have been cemented by later depositions of silica. Strain phenomena and other indications of metamorphic action are here at their maximum. 2. As a by-product of metamorphism filling interstices between the laminae of schists and forming grains in the schists themselves. Quartz of this variety is seen to be composed of separate individual grains sometimes cemented together by additional silica and always shows—at least in all of the ores taken from the Homestake mine—evidence of dynamic stress. 3. As a vein mineral intersecting all schistosity and other superinduced metamorphic structures and therefore entirely subsequent to these. How many periods there may have been during which this vein quartz was introduced it is impossible to say.

Garnet and tremolite of the first or metamorphic group are undoubtedly older than some of the quartz, pyrite, and dolomite that are attributed to mineralization. The garnet especially often occurs shattered and broken, the interstices between the fragments being filled with dolomite, quartz, and pyrite.

Pyrite occurs in many different relations, such as: 1. Along planes of secondary schistosity and other metamorphic structures; it is here unaffected by subsequent movement. 2. In irregular masses and crystals having no definite relation to the schistosity. 3. In irregular masses and crystals which have been shattered by subsequent movement and the interstices between fragments filled by quartz. 4. In the porphyry in minute crystals and rounded grains. 5. As the central and youngest ingredient of quartz veins which cut across the prevailing lamination. 6. In joint planes cutting the schistosity and evidently long subsequent to other mineralizing action.

It will thus appear that the pyrite has been introduced at different periods. One of these periods undoubtedly occurred later than the movements which shattered certain of the metamorphic minerals. It can not, however, be determined whether pyrite belonging to other periods of mineralization may not have been introduced at the time of metamorphism. Again, some of the pyrite is later than the intrusion of the rhyolites, but that belonging to other periods may have been introduced earlier.

Gold.—The relations of the gold afford no evidence as to the date of its introduction. It is associated with quartz, and may have been introduced with the quartz or subsequently. Furthermore, there is no evidence as to the manner in which the gold was deposited.

Dolomite.—The dolomite seems to have been the product of a single period of mineralization. Its relation to fragments of metamorphic minerals shows that it was formed later than the metamorphic action. Its occurrence as fragments in porphyry breccias shows that it was present previous to the movement that shattered the dikes. Again, very heavy strain phenomena, the distortion of cleavages and twining lines, together with its occurrence in lenticular and augen-like masses in bodies of schist, show that much movement and distortion has occurred since its introduction. The relation of the dolomite to some of the quartz is also interesting, for fractures or joint planes filled with glassy quartz occur in the dolomite, and frequently cleavage rhombs and angular fragments of dolomite may be seen surrounded by glassy quartz. The relation of the dolomite and pyrite can not be determined.

The general conclusions which may be drawn from the study of these specimens are as follows: 1. There have been successive periods of movement since the metamorphism of the Algonkian series. 2. There have been successive periods of mineralization which occurred later than the metamorphism of the series. Others may have occurred prior to metamorphism, but of these we have no proof. 3. Though no definite evidence is at hand to show that the gold was introduced into these ores after the metamorphism of the rock, it seems most reasonable to refer it to this period of mineralization.

CLOVER LEAF MINE.

The Clover Leaf mine (formerly the Uncle Sam) is situated on the south side of Elk Creek, at Perry station, on the Black Hills and Fort Pierre Railroad. The country rock is mica-schist and the usual associated rocks of the Algonkian formation—mica-slates, chloritic schists, amphibolites, and quartzites. The mine is situated in the Algonkian area at a considerable distance, in all directions, from exposures of higher geological formations. Pl. VIII (p. 214) shows the geology and general mode of occurrence of the ore body. The mine was first operated under the name of the "Uncle Sam mine," but was abandoned in 1889 on account of the difficulty in handling the water. It was idle for ten years, and was then opened in 1899 by a new company. The deposit was originally worked by an inclined shaft extending southward from a point a short distance north of the large open cut to a depth of 150 feet. This incline, and all of the workings connected with it, are now inaccessible. At a point about 200 feet south of the old incline a vertical shaft was sunk to a depth of 260 feet and the quartz body was then mined in levels from that point. The ore, however, dipped so sharply in a southeasterly direction that it was soon carried beyond working distance from the shaft, and a new incline was opened on a 200-foot level. This followed the ore in a direction S. 64° E. and dipped at an average angle of 40°. This incline had attained a depth of something over 300 feet when the mine was abandoned.

The surface workings of the Clover Leaf mine comprise two open cuts connected by a tunnel. One of these is 120 feet slightly west of north from the shaft; the other about 50 feet farther west. In the first or principal cut is exposed a ledge of iron-stained quartz 5 to 6 feet in thickness, and roughly parallel to the lamination of the schist. It strikes N. 55° W., and dips about 60° to 70° SW. This quartz ledge was followed downward along the dip, and increased greatly in thickness to the southeast. The inclosing schists and slates, as well as the quartz of the ore body itself, are heavily impregnated with pyrite, which at the surface is in a highly oxidized condition.

From the surface to a depth of 300 feet extends a large inclined stope. Through this one may descend as far as the 250-foot level, beyond which water has rendered the workings inaccessible. A horizontal section of the quartz body, as exposed on the 250-foot level, has the appearance of the letter U, with slightly flaring arms. The apex of the U strikes S. 64° E.; the northern arm, N. 40° W., and the southern, S. 75° W. The slates curve over the roof and conform to the strike of the quartz body, appearing on both sides of the northwesterly and the southwesterly arms. They are not, however, exposed in the floor of the stope, from which the quartz has not been completely excavated. Both arms of this quartz mass, when followed out from the crest of the eastwardly dipping anticline, become much narrower than the main quartz body. The northwesterly has an average width, where exposed, of 20 feet; the southwesterly, about 10 to 12 feet, narrowing as it is followed along the strike.

RELATIONS TO SURFACE GEOLOGY.

At a point along the railroad switch, 950 feet in a direction N. 83° W. of the shaft, the lamination of the schists strikes almost east and west with a southerly dip of 44°. This dip and strike seem to prevail along the railroad cut for about 500 to 600 feet, but as one approaches the open cut the dip becomes steeper, and the strike has turned to a direction N. 53° W. On the north side of Elk Creek, 800 feet north of the shaft, is a prominent exposure of schist, and here the dip is 53° toward the northeast, and the strike N. 15° W. The same strike seems to prevail to the northeast of this point. Again, directly south of the shaft, and about 800 feet distant, the lamination of the schists strikes N. 35° W., and dips about 45° SW. All of these observations, when considered together with those made underground, are strongly suggestive of the presence of a southeastwardly dipping anticline, at the crest of which lies the thickest portion of the ore body. The narrower arms would then extend outward, and coincide with the dip and strike, as indicated on the sketch map.

There is a striking resemblance between this ore body and the so-called saddle reefs of Australia.

Owners and operators have indulged in some speculation as to the probable connection of this ore body with that operated by the Homestake Company in Lead. The distance between the two is slightly over 7 miles. The strike of the Homestake ore body is approximately N. 34° W., and this, if extended, would pass a little less than 2 miles west of the Clover Leaf mine. The two mines may perhaps be situated on the same general zone of mineralization, but no conclusions regarding the value of the intervening country can be based upon such speculation.

The mine is singularly isolated from regions of igneous activity, the nearest outcrops of porphyry being about a mile distant. In the mine itself this rock is entirely absent.

CHARACTER OF THE ORE.

The gossan is a ledge of rusty, iron-stained quartz, much fractured and bearing, in hand specimens, no traces of a sedimentary origin. The inclosing rocks are chlorite, hornblende, graphitic schist, and mica-schists of endless variety. These likewise are much stained with iron. At greater depths, however, the rusty stains gradually give place to a heavy impregnation of pyrite, both in the quartz mass and in the inclosing schists.

The gold in the quartz is free and almost invariably associated with galena. A specimen taken from the famous pay streak of the mine, which occurred in the thickest portion of the quartz body as it was followed downward to the southeast, shows a three-eighths inch streak of galena, in a matrix of milky white quartz. In this streak, and completely surrounded by galena, occur nugget-like and irregularly rounded masses of gold, some of them attaining a diameter of one-fourth of an inch. Throughout the entire quartz mass of these specimens are scattered isolated patches of galena, in the center of which could generally be detected a small speck of gold. These smaller masses of gold frequently showed crystal faces.

The average value of the ore is stated to have been from $40 to $400 to the ton, the silver contents being so small as to be generally disregarded; a fact which is rather singular in the presence of so much lead.

COPPER ORES.

There have been found at several localities within the schist areas small deposits of copper. One of these is on the east side of City Creek, near the crest of the hill north of Deadwood. The country rock is a black graphitic schist, in places highly silicified, and in the crevices of this schist occur thin films of native copper. They are scattered through the rock rather sparsely, and occur in patches without regularity, the copper having probably been reduced by the action of the graphite on copper-bearing solutions.

On the crest of the divide between Whitewood and Yellow Creek there is a small prospect in which the quartz-schists and laminated Algonkian quartzites are heavily stained with malachite and a little azurite. Patches of unaltered tetrahedrite also occur. The deposit is small and extremely local. Other areas of schistose rocks in the vicinity of Rochford and a few reported from the southern hills show quartz and schists through which is scattered chalcopyrite mingled with pyrite. The average percentage of copper is very low.

As copper ore is used in the smelting of the refractory siliceous ores, later discussed, these deposits have given rise to some excitement, but none of them has yet proved to be of sufficiently high grade nor uniform occurrence to be profitably worked. If found in large enough bodies the concentration of the chalcopyrite might be carried on with some profit on account of the expense of importing copper ores, but as there is no definite knowledge as to the length of time that the refractory siliceous ores will continue to be productive, the exploitation of copper deposits, unless in extremely large and uniform bodies, should be carried on with great caution.

TIN ORES.

Tin has been known to occur in the southern hills since 1876, when attention was first called to it by Richard Pearce, who had detected it in some gold dust sent him for examination; but its presence in the Nigger Hill district does not seem to have been appreciated until the discovery of tin at the Etta mine (originally a mica mine) in 1883. This discovery stimulated the search for other deposits, which resulted in several finds in the vicinity of Nigger Hill and Sand Creek and the prosecution of quite a little development work. The enormous expenditure of capital and the collapse of the tin enterprise in the southern hills, however, brought all operations for the exploitation of tin ores to an abrupt termination. Since that time but for a few ineffectual attempts to interest capital in these deposits little or no work of any kind has been attempted. At present writing, however, the writer is informed by Mr. W. S. Tangier Smith that there has been a renewal of activity in the prospecting in and about this northern district.

In general, Nigger Hill comprises a central area of crystalline Algonkian rocks and intruded porphyries of probable Eocene age, from which the sedimentary rocks of Cambrian, Silurian, and Carboniferous age dip away in all directions—a repetition in miniature of the main Black Hills uplift. For this general uplifted region the name Nigger Hill is frequently used; but more correctly applied, it indicates a slightly elevated ridge of limited areal extent situated between the headwaters of Sand Creek and Bear Gulch. It is on this ridge that the most extensive bodies of tin-bearing granite have been found. The country rock throughout the major portion of the uplifted area is prophyry of Tertiary age, which has been intruded into the Algonkian rocks in such extensive masses as to have left only small portions of them exposed. Of these remaining portions perhaps about one-half is crystalline schist, the other half being irregular, lenticular masses of a coarse, pegmatitic granite which is composed of feldspar (orthoclase or albite), muscovite, and quartz. Both granite and schist, as well as the acidic types of porphyry, are cut by basic dikes. The granite masses trend in a general north-northwest direction. The largest of them has been found on Nigger Hill. It is completely surrounded by porphyry, being more in the nature of an inclusion in the intruded porphyry than a lenticular mass in the Algonkian schists. The exact form and character of this, as well as the other granite masses, has not been determined, for the country is heavily cloaked by vegetation and the mines at the time of examination were completely inaccessible.

The cassiterite occurs in two forms: (1) In the pegmatitic granites and (2) as stream or placer tin, which has been derived from them.

In the first mode of occurrence it is found in irregular grains, which range from one-eighth to one-half inch in diameter. The grains are most frequently without crystal faces, but occasional large and fairly perfect crystals have been found. They are most frequently embedded in the white feldspar which forms the major portion of the granitic matrix, but they also occur in those portions of the granite which consist almost entirely of quartz and mica. No spodumene has yet been reported, but columbite and tantalite have been detected both in the lode ores and in the stream tin; some tourmaline and wolframite are also found.

While it has not been possible to form any very satisfactory idea as to the exact character of these deposits, it seems probable that they were formed contemporaneously with the granites in which they occur.

Whether these ores may or may not be profitably worked is a question which only extensive exploration will determine. The percentage of tin in the rock is small, probably not exceeding 2 per cent,[a] and the distribution of the cassiterite in the rock is extremely irregular, so that a profitable exploitation at one time might readily become a losing enterprise at another. If operated upon a small scale it is possible that these ore bodies may be successfully worked.

STREAM TIN.

The stream tin which occurs in some quantity in the gulches in this region has occasioned much annoyance to the miners in their gold panning since the early seventies. It was, as Doctor Carpenter describes, known as "iron" until 1883. Many attempts have been made to work these gravels and with some success, but no extensive shipments have been made. The tin occurs in subangular fragments, which

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[a] Blake, W. P., Trans. Am. Inst. Min. Eng., vol. 13, p. 691. Carpenter, F. R., Trans. Am. Inst. Min. Eng., vol. 17, p. 572 et seq. Headden, W. P., Proc. Colorado Sci. Soc., vol. 3, pp. 347-350.

range from an inch or more in size down to extremely minute grains. They are mingled with many small red garnets, pieces of columbite and tantalite, and minute crystals of topaz. The cassiterite rarely shows the dark reddish coating so frequently observed in stream tin, but it is generally in black shining fragments, which are only slightly rounded and bear evidence of having been transported to no great distance from their source.

MISCELLANEOUS DEPOSITS IN THE ALGONKIAN ROCKS.

At several localities within the productive mining region ores have been found which may be properly described with the Algonkian lodes. They occur partially in eruptive rocks and partially in brecciated material composed of schists and porphyry, while at times they form veins which pass from one rock into the other. At other points they pass from porphyry into Cambrian rocks. While none of these has yet attained any great importance, there are two that deserve special mention. The first is in Strawberry Gulch, where a number of small mines have been intermittently worked, among them the Hoodoo, Gilt Edge, Jupiter, Dakota Maid, and Union Hill. The ore generally occurs in a decomposed porphyry in the form of thin auriferous limonite fillings of small fractures, or of impregnations in the adjacent rock. In general, these pass downward into unoxidized pyrite, while in a few cases sphalerite and galena have been reported. The porphyry mass in which these ores are found is extremely large and so irregularly intruded into the schists that its relations to them can not be readily made out. Some of the ore obtained from the mines is reported to have been very rich, but it has so far been too irregular in its occurrence to form the basis of extensive mining.

The second locality where ore has been found in porphyry is at the Old Ironsides mine, near the mouth of Squaw Creek. Here there is exposed in the side of the creek a sheet of mica-diorite-porphyry about 40 feet thick with beds of Cambrian rock both above and below.

Through these rocks run a series of vertical fractures, striking about N. 85° E., along which silicification has occurred and from which telluride of gold has been introduced into the adjacent rock, often to considerable distances from a fracture. Some of the crystals of telluride (presumably sylvanite) are very large.

The deposition has occurred chiefly in the diorite-porphyry, but also to a minor degree in the Cambrian rocks. At the surface, where the rocks are highly oxidized, gold may be seen along the fractures in the free condition.

There are other places in which ore has been found in eruptives, either as fillings of fissures or as impregnations, but they are not of any economic value. The eruptives, as a whole, however important they may have been in connection with the genesis of the ore bodies, have not themselves been the loci of considerable deposits.

CHAPTER II.

ORE DEPOSITS IN CAMBRIAN ROCKS.

The ore deposits in Cambrian rocks are second in importance only to those of the Algonkian. They have of late years produced heavily, and have closely approximated the Homestake mine in their aggregate output. They may be subdivided as follows:

- Gold and silver ores
  - Gold-bearing conglomerates.
  - Refractory siliceous ores.
  - Pyritous ores.
- Tungsten (wolframite) ores.
- Lead and silver ores.

GOLD AND SILVER ORES.

GOLD-BEARING CONGLOMERATES.

GENERAL STATEMENT.

At the base of the series of Cambrian strata, which lie unconformably upon the upturned metamorphic schists of the Algonkian, a conglomerate is usually present. It varies in thickness from a few inches to more than 30 feet. At a few localities it is entirely absent, but in general is so prominent a feature of the series that it has been recognized as a separate formation. Throughout the larger number of areas where the Cambrian strata yet remain uneroded this conglomerate is characteristically about 3 or 4 feet thick and passes upward into a hard, dense quartzite that has a vertical range of from 15 to 30 feet, the conglomerate itself being often cemented by more or less indurated sandstone of a quartzitic nature. It is present in this development in the vicinity of Bald Mountain, Garden, Woodville, and many other places. There are, however, two localities where it attains an unusual thickness. The first is known as "Cement Ridge," and is on the west side of Spearfish Canyon; the second is the region in and about Lead. In the latter locality only it is auriferous and has yielded large amounts of gold. The conglomerate here has a thickness of from 2 to 30 feet and lies at the base of small outliers of Cambrian strata that remain upon the summits of divides. The region is one of prevailingly Algonkian rocks, into which streams have carved deep and irregular gorges. The conglomerate is overlain by cross-bedded beach sands and quartzites, which are in turn conformably overlain by the higher members of the Cambrian series. It is underlain unconformably by metamorphic schists and slates. In these underlying Algonkian rocks is a great mineralized zone of relatively indurated character, which strikes approximately N. 34° W.—almost parallel to the lamination of the schists. This zone was probably a reef in the old Cambrian sea at the time of the deposition of the conglomerates, as it offered more resistance to erosion than the encompassing schists on account of the hardness imparted to it by pre-Cambrian mineralization. Upon this zone are the workings of the Homestake, Father de Smet, Deadwood-Terra, and Columbus mines, and about it are the productive portions of the auriferous basal conglomerates of the Cambrian. They are five in number; one, comprising the Durango and Harrison mines, is west of the Homestake lode near its southern extremity; the other four, east and north of it, include the Hawkeye, Monitor, Gold Finch-Gentle Annie group, the Bobtail Gulch groups, and a fifth mine on the divide between Deadwood and Blacktail gulches (see Pl. VI, p. 214). The gold-bearing conglomerate occupies depressions in the old Algonkian surface, but thins out to nothing along the strike of the Homestake lode, where the higher measures of the Cambrian lap over onto the mineralized rocks of the Algonkian. A general downward inclination of the Algonkian surface toward the northeast also exists, but as this corresponds to a northeastward dip in the Cambrian it is probably due to later distortion of the Algonkian surface. Beyond the limits of the area in which this thick, gold-bearing conglomerate occurs the basal Cambrian conglomerate becomes very thin and quartzitic. It is impossible to give the exact boundaries of its original extent on account of the dissected nature of the areas now remaining. Lithologically this auriferous conglomerate is formed of rounded waterworn pebbles of quartz or Algonkian quartzite with an intersprinkling of schist fragments which seem to decrease in abundance as one proceeds farther from the Homestake lode. It may be at once distinguished from the non-gold-bearing portions of the basal conglomerate, as it is cemented by either oxide of iron in the weathered portions or by pyrite when it has not suffered alteration. The nonauriferous conglomerate, on the other hand, has always a quartzitic, or in rare instances a slightly calcareous matrix. The pyritic cement occurs in all the productive areas except one, and as all degrees of oxidation are present it can be assumed that the matrix of all of the gold-bearing conglomerate was once pyrite.

Much of the gold in the richest conglomerates is detrital, as proved by its waterworn condition and its concentration near the bed rock. This gold was derived undoubtedly from the erosion of auriferous lodes in the Algonkian rocks and was mechanically deposited in depressions along the old Algonkian shore line. Some of the gold was dissolved by ferric sulphate resulting from the oxidation of the pyrite, and from this solution was redeposited in thin films in the schists below. This has also produced an enrichment of the lowermost layers of conglomerate. In addition to these it is possible that gold was introduced with the pyrite that once formed a large portion of the matrix of the pebbles. To determine this, careful assays were made in the only productive area now completely accessible—that which includes the Gentle Annie, Monitor, Gold Finch, and Hawkeye mines. The mode of occurrence may be seen in Pl. XVIII (p. 214). It was found that along definite lines in the center of the stopes there were values of from $5 to $12 per ton in the conglomerate, while at a distance of from 10 to 100 feet from such lines the values sink to between $1 and $2 per ton. Iron-stained fractures are found in the roofs of these stopes. A possible inference is that the gold which has low and fairly uniform values distributed through the mass is of detrital origin, and that the additional values have been introduced into the conglomerate together with the pyrite along zones of fracture. This is rendered still more probable by the fact that much of the gold does not yield to simple amalgamation, the conglomerate being treated largely by the cyanide process. The introduction of the pyrite was subsequent to the deposition of the conglomerates, since mineralization extends into fractures in the quartz pebbles. The pyrite is probably a replacement of the original cementing material, which elsewhere consists of quartzose sands.

Intrusions of rhyolite cut the conglomerate in some places. They are much mineralized with pyrite, which is thought to be of post-intrusive origin. This would place the pyritic mineralization subsequent to the rhyolite intrusion.

These gold-bearing conglomerates must have been either of fluviatile or of littoral origin. All of the evidence is in favor of the latter view, for (1) the rocks immediately above the conglomerates contain marine fossils and were unquestionably deposited in an extensive Cambrian sea; (2) the area covered by the heavy conglomerates is very small and quickly passes in all directions into regions where finer material with marine shells shows that the conditions were marine; hence, a land surface sufficient to support a drainage extensive enough to deposit such heavy conglomerate could hardly have existed; (3) cross-bedded sands and quartzites were deposited upon the conglomerates with perfect conformity so that they are to be considered as an integral part of a typically marine series; (4) conglomerate is absent from the outcrop of the Homestake lode which must therefore have projected above the old pre-Cambrian surface; (5) schist fragments, such as could only have been preserved near the source from which they originated, decrease in abundance as one proceeds outward from the Homestake lode. While, therefore, these were littoral deposits they were exceptional in that they were not uniformly deposited along the shore, but were confined to the vicinity of the outcrop of a large gold lode, and the detrital material from that lode was held in irregular depressions in the submarine surface in its vicinity.

The points in which the views herein expressed differ from those of previous writers are: (1) The recognition of pyrite as once the matrix of these auriferous gravels; (2) the reference of a considerable portion of the contained gold to the action of mineralization long subsequent to this deposition.

DETAILED DESCRIPTION.

LITERATURE.

In the only previous description of these basal conglomerates or "fossil placers," as they have been termed, W. B. Devereux[a] has described in a general way their geological occurrence and the manner in which the gold is present in them. Since gold-bearing conglomerates as features of strata of very early geological periods have nowhere else been found, this paper has been widely quoted in many publications relating to mineral deposits. Since its publication many of these mines have been worked out and are now in most cases abandoned, so that they afford but poor facilities for investigation. In not a few cases, however, examination has been possible and several important features not observed by Devereux have been noted. Devereux's paper is too long for complete citation at this point, but a short statement of the main facts and the conclusions deduced is given below. For further detail the reader is referred to the original.

In the vicinity of the Homestake vein in the Black Hills are a series of detached areas of Cambrian strata with beds of conglomerate at the base and resting unconformably upon metamorphic schists, from which the materials requisite for the formation of the conglomerates have been derived. They consist of quartz, pebbles, and schist fragments, with frequent hematite bowlders, and are cemented by oxide of iron, but in some instances take on the character of a breccia. They contain gold and have been extensively mined, most of the productive deposits being found on the east side of the Homestake lode; a single deposit occurs on the west side. The Algonkian surface upon which they rest is slightly undulating and slopes away from the Homestake lode in a northeasterly direction, at an angle of about 10° and nearly perpendicular to the the strike of the Homestake lode, so that the Cambrian sediments form a wedge thinning out to nothing on top of the Homestake lode, where the cap of rhyolite comes in contact with the vein matter itself. This proves that the thinning was not due to subsequent erosion. Toward the east this wedge-shaped mass becomes much thicker. A section (fig. 12) is given to illustrate this. The richest deposits were mined from the divide between Deadwood and Blacktail gulches. The gold was a mechanical deposit of water-worn scales and "shot" gold, richer near the base of the conglomerates, so that only the lower 5 or 6 feet paid for milling and mining.

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[a] Trans. Am. Inst. Min. Eng., vol. 10, pp. 465-475.

Local channels and depressions in the Algonkian surface caused concentrations and enrichments, but the richest portions were sometimes found a little to one side of the center of depressions, as if caused by wave action. Alternations of rich and poor material occurred, due to currents. The gold was in a finer state of division than that in the Homestake vein and carried less silver; probably on account of the solution of silver by sea waters at the time of deposition and the solvent action of the ferruginous solutions that formed the matrix of iron oxides that cements the pebbles. Intrusions of porphyry produced heat that later assisted this solution. The proof of this is that the gold near the porphyry was either completely dissolved out of the conglomerate or exhibited a pitted surface due to solvent action. The gold was almost always coated with a film of iron oxide. A further proof of the solvent action of the waters on the gold is that it is often chemically precipitated in thin, continuous films in the schists below the conglomerates. Placers of recent formation occurred in Deadwood and Blacktail gulches, and were formed by the disintegration of the fossil placers above and, with the exception of Blacktail Gulch, by additional accessions from the erosion of the Homestake ledge. Cement gold yields 89 to 93 per cent extraction by free-milling methods. He then concludes as follows:

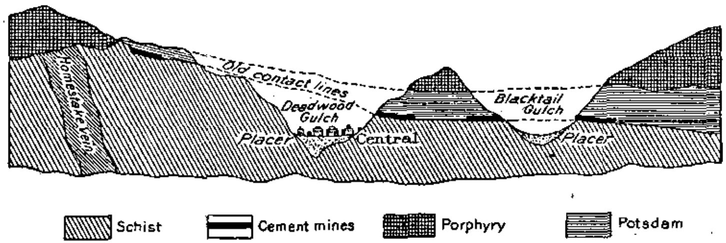

FIG. 12.—Approximate geological section from Homestake eastward. (After W. B. Devereux.)

“If we now endeavor to group together the facts noted above, it does not seem a difficult undertaking to form a history which shall give a rational account of the successive geological changes which took place. First, we have the proof that the gold grains and the contained gold were in existence, in much their present condition, prior to the Potsdam period. Then, we have the Potsdam seas washing away the débris resulting from the disintegration of the quartz veins, and depositing it in deeper water in accordance with its various specific gravities. At the same time the gradual wave action carried the gold to the bed rock in the same manner that it is settled in a miner's pan. The Homestake vein, by reason of its greater durability, formed a reef or low island which never became deeply submerged. After a time these sediments became insular, and as such remained undisturbed, gradually becoming cemented into rock until the recent eruptions of porphyry took place causing intense local metaphoric action. The gold, which up to this time suffered perhaps loss in silver only, now became itself partially dissolved where the solvents were sufficiently powerful, and was again at least partially precipitated as thin films in the schists below.

“Once more a period of rest occupied the time until the erosive action of fresh-water streams cut through the upper strata and began to disintegrate the matrix of the gold and afforded material for a new concentrating process. Disintegration and concentration has been going on until now, when the hand of man has hastened the work of nature.

"This gold from the conglomerate, which found its way down the slopes to the gradually lowering bottom of Deadwood Gulch, was joined with new supplies brought from the Homestake vein through lateral gulches, and the result was the great Deadwood placer. That in Blacktail Gulch, however, received no new accession and remained a placer, which had received its gold entirely from the Potsdam sediment."

The remainder of the paper is devoted to the refractory siliceous ores and does not concern the present discussion.

LOCATION.

The area in which the auriferous conglomerates occur is a restricted one, embracing only a little over 2 square miles, extending from the southern edge of Lead northward to the northeast side of Blacktail Gulch. The accompanying map (Pl. VI, p. 214) shows the location and extent of the area, also the distribution of the gold-bearing conglomerate.

TOPOGRAPHY.

After the erosion of the cover of Paleozoic sediments which formerly overlay the region streams trenched deep and irregular gorges into the schists, slates, and quartzites of the Algonkian. The deepest of these is the gorge, Deadwood Creek, which flows toward the east about a mile north of Lead and empties into Whitewood Creek at the city of Deadwood. Through Lead a parallel gulch of less depth, known as Gold Run Gulch, extends toward the town of Pluma, where it empties into Whitewood Creek. Poorman Gulch is a transverse valley that runs northwest into Deadwood Gulch upon the west side of Lead. Blacktail, Sawpit, and Treasure gulches, join Deadwood Gulch from the northwest. Bobtail Gulch and a corresponding valley on the south side of the divide that intervenes between the two first-named streams empty into Deadwood Gulch and Gold Run Gulch, respectively.

GEOLOGY.

ALGONKIAN.

As the Algonkian rocks have been described in detail in the foregoing pages they will not be again referred to here except with reference to the Homestake ore body.

The Homestake ore body consists of a series of broad lenticular masses of Algonkian rock in part silicified and impregnated with pyrite. It forms a broad band in the schists of an average width of 150 (?) feet and strikes about N. 34° W., approximately following the schistosity of the Algonkian series.

Taken as a whole this ore body forms a long zone that pitches in a general way toward the southeast and has, on account of the induration imparted to it by mineralization, been much more resistant to erosive action than the inclosing rocks. For this reason it probably formed at early geologic periods a prominent feature in the old pre-Cambrian surface.

CAMBRIAN.

Upon the crests of the Algonkian divides that separate the streams above described rest small detached areas of Cambrian strata. The pre-Cambrian surface was of an undulating character, and in the depressions of this surface lie the thickest and richest portions of the auriferous conglomerate. Passing vertically upward from the Algonkian the conglomerates are overlain by fine-grained, cross-bedded, and now consolidated beach sand containing many scales of mica, some argillaceous matter, and little, if any, carbonate of lime. These in turn pass into quartzite, often cross-bedded and containing subsidiary layers of conglomerate, none of which attain any considerable thickness. Still above the quartzite are beds of variable width, composed of a banded, somewhat impure dolomite of crystalline texture, now stained red and yellow by oxide of iron. Above this in turn lie argillaceous and often slightly glauconitic shales. Over the shales is a heavy cap of fine-grained rhyolite, which is often connected with dikes that extend upward from the Algonkian through the Cambrian. The regularity of sequence is interrupted by two disturbing conditions. First, the rhyolite cap often takes a slightly downward flexure so as to cut out much, if not all, of the Cambrian rocks; and, second, the higher portions of the pre-Cambrian surface rise so that conglomerate, beach sand, quartzite, and finally dolomite and shales lap over onto the Algonkian measures.

DISTRIBUTION OF THE CONGLOMERATE AREAS.

On the divide west of the Homestake outcrop and between the heads of Poorman and Gold Run gulches is a broad trident-shaped area of Cambrian strata with its three prongs extending eastward along the tops of the ridges between Bobtail and Homestake gulches. The northern arm lies above the De Smet cut, and its connection with the main area has been severed by erosion. The central arm is capped by a remnant of rhyolite sill, mentioned above, the porphyry forming three elevated knolls connected by a narrow ridge of the same rock. The Cambrian is here very thin, and the basal conglomerate is almost entirely absent, the dolomitic shales being separated from the schists by only a small 6-inch layer of pebbles. The southern arm is short and broad and is interrupted by a rhyolite sill and capped with a remnant of the same rock. The rhyolite has been eroded from the main area with the exception of two small outliers. Along the western edge of this area the conglomerate is from 4 to 6 feet thick, but increases toward the southeast to 15 feet; thence it pinches out so that the dolomitic beds lap over onto the western side of the Homestake outcrop. At the head of Homestake Gulch the conglomerate is absent except for a few inches scarcely worthy of mention. On the central arm the conglomerate is also absent. On the detached northern extremity, between Bobtail and Deadwood gulches, it is lacking in the immediate vicinity of the De Smet and Deadwood-Terra cuts, but appears just east of them, and thickens as it is followed in a northeasterly direction until it has attained a thickness of perhaps 20 feet.

Another large area of Cambrian is that east of this and situated between Gold Run and Deadwood Gulch. At the western end, in the neighborhood of the Caledonia cut, the conglomerate is absent, but it thickens to the east until about 400 feet from the Caledonia it has attained a maximum thickness of 8 or 12 feet. Eastward from here the Algonkian surface rises slightly again, and the conglomerate, while present, becomes so interrupted by beds of quartzite and consolidated beach sand as to have afforded no workable deposits. The rhyolite cap is 150 feet thick between it and the Algonkian, but there is a considerable thickness of Cambrian. South of Gold Run is another exposure where conglomerate with a thickness of 8 feet has been found. North of Deadwood Gulch is a wedge-shaped area of Cambrian extending southeast onto the narrow divide between Deadwood and Blacktail gulches. The conglomerate here is upward of 30 feet thick, but is interrupted by quartzite beds at the east end of the divide. The Algonkian surface dips northeast and is lower in elevation than on the south side of the gulch by upward of 150 feet. In the head of Hidden Treasure Gulch the conglomerate is reported to have been very thick. On the north side of Blacktail Gulch the Algonkian surface slopes northeast, and 22 feet of conglomerate is here found considerably lower in elevation than that south of the gulch. An extensive sill of rhyolite, 350 feet in thickness, covers all of the country to the north and comes down to, and in places through, the conglomerate.

There are five localities at which auriferous conglomerate has been mined (Pl. VI). The only deposit mined on the west side of the Homestake outcrop is that which lies just west of the porphyry knoll upon the southern arm of the Poorman Gulch area. There are here two mines, the Durango and the Harrison. The Durango is opened by a shaft which is north of the Black Hills and Fort Pierre Railroad, and exposes 15 feet of conglomerate lying upon the Algonkian schists. Pyrite forms the cement of portions of the conglomerate. Not far east of the Durango is the shaft of the Harrison mine, in which is also exposed 15 feet of gold-bearing conglomerate. The Algonkian rocks that underlie these deposits are reported to slope upward on the east, and the conglomerate itself, as exposed on the east side of Poorman Gulch, is much thinner, so that it is probable that this coarser material lies in a northwestwardly trending depression in the Algonkian surface, parallel to the Homestake outcrop.

The next deposit of conglomerate is that which lies east of the Caledonia cut and upon it there are three large mines—the Monitor, at the head of the small gulch which connects with Bobtail; the Gentle Annie, at the head of a northwardly flowing stream that joins Deadwood Creek, and the Hawkeye, which comprises a large set of workings on the southeast side of the ridge. These mines have been operated upon a bed of conglomerate ranging from 2 to 12 feet in thickness, and lying in irregular channel-like depressions in the Algonkian, from which the rocks of that series rise sharply to the west and more gradually toward the east. The larger portion of the conglomerate is cemented by pyrite. The Monitor workings comprise large stopes, often more than 100 feet in width, and sometimes over 12 feet in height. In the Gentle Annie mine a sill of porphyry underlies the greater portion of the conglomerate and gradually rises toward the south. The gold in these mines occurs along definite lines and usually beneath an even bed of loosely compacted, slightly argillaceous sand. In the roof of the stopes many intersecting fractures can be observed, but their directions were not accurately determined.

The third productive area is situated upon the northeastwardly sloping Algonkian surface of the divide between Bobtail Gulch and Deadwood Creek. In the vicinity of the Deadwood-Terra mine this conglomerate partakes of the nature of a breccia. It is all of the oxidized variety and the pebbles are imbedded in a matrix of iron oxides. It comprises three mines—the Deadwood-Terra mine, nearest to the Homestake ore body; the Omega mine, lying to the northeast, and the Pinney open cut, which has been excavated from the very narrowest part of the divide upon a portion of the conglomerate which was exposed at the surface, but has now been completely removed.

North of Deadwood Gulch, and on the divide between it and Blacktail Gulch, is the fourth and richest area of gold-bearing conglomerate. Upon this area there were operated three mines—the Baltimore and Deadwood on the extreme eastern end of the divide, the Esmeralda upon the north side a little to the west of the Baltimore and Deadwood, and the Hidden Treasure mine on the western edge of the area. None of these mines is now accessible, but the conglomerate in the Hidden Treasure mine is reported to have yielded extremely large amounts of gold. The Algonkian surface slopes upward gradually toward the northwest, and is reported to have finally encountered a northeastwardly trending rise, which cuts out all but the upper measures of the Cambrian series. The conglomerate at this point is not now to be seen, but is reported as of great thickness.

The fifth area is on the north side of Blacktail Gulch, northeast of the last named. It comprises the Minerva and the Deadbroke mines. From the tunnels of these two mines, which run northerly from the base of the hill slope, the Algonkian surface slopes sharply downward toward the northeast. At the entrance most of the conglomerate is cut off by a capping of rhyolite which comes completely down to the

Algonkian, but it thickens to more than 22 feet at the northern end of the mines, about 600 feet northeast from the entrance. Part of the conglomerate in the Minerva mine is still in an unoxidized or pyritic condition, but the larger portion of it is cemented by iron oxides.

Of these five productive areas the richest was that upon the divide between Deadwood and Blacktail gulches. Some of the conglomerates taken from there, according to Devereux, yielded $50 per ton.[a] Ore from the Pinney open cut, on the divide between Bobtail and Deadwood gulches, is also reported to have been very rich, and likewise some of that taken from the Deadwood-Terra mine. That from the area east of the Caledonia open cut was characteristically lower in gold contents. That on the northeast side of Blacktail Gulch does not, as a rule, yield more than $4 per ton, while in the Durango, on the west side of the Homestake vein, it is also of low grade.

LITHOLOGICAL COMPOSITION.

The gold-bearing conglomerate is composed, as stated by Devereux, of the débris derived from the disintegration of the Algonkian rocks. Rounded, waterworn bowlders and pebbles of quartz and laminated quartzite are the most common, and range in size from one-half of an inch to 1 foot in diameter. The larger ones are not very frequent, and a fair average size for the majority of pebbles is probably from 1½ to 3 inches. Many smaller and many larger ones occur, but they are insignificant in number. Fragments of schist, often 3 or 4 inches in length and more or less rounded, occur intermingled with the other pebbles, but they are not abundant. They occur with greater frequency in the Omega and Hawkeye-Pluma mines than in the Deadbroke and Minerva—that is, they are in greater numbers near the old shore line from which they were derived. Devereux mentions many pebbles and bowlders of hematite, but none were observed by the writer. Between the pebbles and schist fragments are many small, rounded grains of waterworn sand, scales of mica, and smaller pebbles. The whole is cemented together by material which, in the gold-bearing areas, is in large part either pyrite or iron-oxide, while the non-gold-bearing portions are cemented by a quartzitic matrix.

PYRITIC CONGLOMERATE.

When the matrix is pyritous the conglomerate is extremely tough and breaks with difficulty. The spaces between the pebbles are often incompletely filled, so that cavities are left in the pyrite with their interiors coated with drusy crystals of the same mineral. Such cavities as this are frequently encountered in mineral deposits formed by the replacement of one mineral by another where the aggregate volume of the material introduced is less than that removed. They may be considered an important proof of replacement action. Extensive bodies of this pyritic con-

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[a] Trans. Am. Inst. Min. Eng., vol. 10, p. 468.

glomerate are found in the Pluma, Monitor, and Gentle Annie mines and isolated patches occur in the Minerva mine on the north side of Blacktail Gulch; also in the Durango mine on the west side of the Homestake lode. In other words, all of the areas where the auriferous conglomerate has been mined show greater or less amounts of an unoxidized pyritic matrix, the single exception being the Deadwood-Terra-Pinney area, between Bobtail and Deadwood gulches, where the cement is wholly limonitic. This pyritic matrix was not observed by Devereux, probably on account of the limited amount of development attained at the time his observations were made.

CONGLOMERATE CEMENTED BY IRON OXIDE.

Of the gold-bearing conglomerate already mined probably four-fifths of the total bulk has been oxidized. This oxidized conglomerate has a cement of iron oxide, sometimes exhibiting cavities, but most frequently constituting a moderately hard, uniform material of reddish to dark-brown color. In cases where oxidation has gone very far, the conglomerate is loosely compacted, but in general blasting is necessary to remove it. In places it has been resilicified by waters that have penetrated it along lines of fracture.

The continuity of these conglomerates is frequently interrupted by beds of quartzite, often cross bedded and containing subsidiary layers of pebbles; also by bands of loosely consolidated somewhat clayey sand in thin flaggy layers, which contain many scales of mica. Such interruptions are always accompanied by a decrease in the gold contents. In places quartzite beds become so abundant that the conglomerate gradually dwindles to nothing. Again, there may be two beds of coarse, ferruginous conglomerate separated by a parting quartzite. In general, however, the gold-bearing portions of the conglomerate lie in more or less channel-like depressions, and a transition laterally into quartzite and sand layers, where seen, is accompanied by a rise in the Algonkian surface.

ALTERATION OF THE CONGLOMERATE.

There is little question that the matrix of all of these ores was at one time pyritic, for pyrite is still present over extensive areas. It disappears gradually as one passes into the oxidized material occurring in isolated patches in all but one of the areas of oxidized conglomerate.

The process of oxidation is still going on in many places. In the Pluma mine a drift had been run through completely fresh pyritic conglomerate and was left for some years. The walls are now coated with a thick layer of glistening crystals of melanterite, many of them of singular beauty and perfection. A fine whitish-green layer of the same mineral is often present and may be identified by its slightly acrid taste. This indicates that ferrous salts are the first to form in the oxidation of the pyrite, and such is in accord with recent investigations by Dr. H. N. Stokes. As will be later apparent, these sulphur-iron compounds have an important bearing upon the solution and reprecipitation of a portion of the gold.

THE CONTAINED GOLD.

The gold is known to occur in two conditions: detrital gold and chemically reprecipitated gold; in addition much of it may have been introduced with pyrite.

MECHANICALLY DEPOSITED GOLD.

Apparently the detrital gold was in the early developments the most important source of value in the ores. Of it Devereux remarks:[a] "The gold had all the characteristics of 'placer' gold and was generally what is called 'shot' gold, or smooth, rounded grains slightly flattened. I observed one nugget of nearly 3 pennyweights in weight."

The writer has noted occurrences in which gold, such as that described, was found in considerable quantity. A nugget of about the size of the one mentioned was seen embedded in the iron-oxide cement. It is well rounded and nearly one-half inch in diameter, and is of undoubted detrital origin. Many fine scales, showing the characters of waterworn gold, may be seen in addition to the coarser grains. As a rule, gold can not be seen in the conglomerate either in the sulphide or oxidized variety without the aid of panning. The distribution of this detrital gold through the conglomerate is dependent on two conditions: First, that of specific gravity; second, that of the alternations of rich and poor materials due to varying conditions of deposition. The gold occurred largely near the bottom of the conglomerate and not far from its contact with the schists. "In general," says Devereux, "only 5 or 6 feet in thickness will pay for mining and milling." It is usually distributed more thickly at the bottoms of the stopes immediately overlying the slates. Devereux remarks:[a]

> "In general where conditions had been such as to allow the subsidence of other materials of high specific gravity the gold was most abundant, ordinarily with large quartz bowlders or with pebbles of hematite. The latter were seldom found without gold being attached to them, the pebbles themselves having a smooth polished surface. In general, the position of the gold was always such as to point to its great specific gravity as the locating cause and not to solution or precipitation. In fact, the many curious positions in which I observed the gold were such that no satisfactory explanation could be found except the one noted above. Upon one quartz bowlder, which had lain directly upon the schists, I found, after removing the decomposed talc from the bottom, that grains of gold of almost exactly the same size were arranged in ribbon-like layers in such quantity that half an ounce could probably have been covered by the hand. Each grain of gold is generally covered with a thin coating of oxide of iron, which needs a blow to loosen it."

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[a] Trans. Am. Inst. Min. Eng., vol. 10, p. 469.

It is to be regretted that the writer was unable to see more occurrences of detrital gold in these conglomerates, but the mines are now but little worked and such operations as are being carried on involve leaching in cyanide tanks, little or no free gold showing in the ore. The opinion of Devereux, however, as to the detrital nature of the gold is based on a wide range of observations made while engaged in mining work and may therefore be assumed to be accurate. Furthermore, they are in accord with such observations and panning tests as the writer was able to make, and there seems to be no doubt that a large portion of the gold in these conglomerates, especially in the richer workings in the pyritic or oxidized condition, is of detrital origin and has been derived from the erosion of the Algonkian lodes.

CHEMICALLY REPRECIPITATED GOLD.

A number of assays made by Devereux seem to show that the detrital gold contains less silver than that in the neighboring lode ore deposits, and this is in the line of observations in other regions,[a] placer gold generally being purer (containing less silver) than that occurring in veins. This is usually attributed to the greater solubility of silver over gold. Devereux supposes that the solution may have been due to the action of sea water at the time of deposition, or of later ferruginous waters. The former is possible but not susceptible of proof; for the latter Devereux himself cites instances where thin films of gold are present along the lamination planes in the schists below the conglomerate, and gives instances where as much as 10 feet of bed rock paid for mining and milling; the writer has also seen deposits in the Deadbroke mine where schists for a depth of 3 feet below the ore are reported to carry about $3 per ton in gold. Similar conditions are also said to obtain in other oxidized localities. Now, as has been shown, the matrix of the conglomerate is pyritic. As this was oxidized from the surface downward solutions of ferric sulphate would be formed by descending surface waters, which would take up in solution both gold and silver. As this ferric sulphate came in contact with pyrite the dissolved metals would have been precipitated, the gold more readily than the silver, owing to the superior solubility of the latter. Thus, the bottom of the conglomerate beds and the underlying schists would have been enriched by the reprecipitation of the gold, but the silver would have been carried farther.

GOLD INTRODUCED WITH PYRITE.

It is evident that the introduction of the pyrite into the conglomerates is the result of mineralizing action subsequent to deposition, for it occurs in fractures in the pebbles and contains cavities lined with crystals, such as may frequently be observed in replacement deposits. That gold was actually introduced with the

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[a] Trans. Am. Inst. Min. Eng., vol. 9, p. 636.

pyrite seems probable, but is hardly susceptible of definite proof. The facts bearing upon this point are as follows: In the Hawkeye-Pluma mine there is a stope 500 feet long in which large pillars have been left to support the roof. The conglomerate is from 5 to 8 feet thick and is largely oxidized, but passes into the pyritic variety at the north end. A series of assays made in this stope showed values of about $6 to $8 per ton confined almost entirely to the pillars, but no values in the sides of the stopes higher than $2 per ton, although in many instances there was little change in the character of the conglomerate. Two other stopes in this mine showed the same phenomenon. Fractures, stained with iron and somewhat silicified, occur in the sandy material that forms the roof. In this case the rock is richer where the pyrite is most abundant—that is, along the medial lines which appear to be lines of fracturing and hence channels for the admission of solutions. Unfortunately, it does not seem possible to determine what proportion of gold in the pyritic conglomerate is detrital or was there before the pyrite was introduced. There is also a possibility that some of the gold in the lower and unoxidized portions may be reprecipitated gold resulting from secondary concentration.

REFRACTORY SILICEOUS ORES.

GENERAL STATEMENT.

Of all the ores occurring in rocks of later age than the Algonkian the refractory siliceous ores have thus far been the most important factor in the gold production of the northern Black Hills. Their yield has increased rapidly and is now equal to about two-thirds of the output of the Homestake mine. They exhibit a very marked uniformity in occurrence and may be considered to be of rather unique character.

These ores have been variously termed "Potsdam gold ores"[a] and "Siliceous ores," the latter name having prevailed more widely than the other in mining and geological circles. Of these the name "Siliceous ores" alone, based upon the mineralogical composition of the ore, is inapt, as it does not serve to distinguish the ores from others whose characteristic quartzose gangue is unaccompanied by refractory character. Again, the term "Potsdam" is to be excluded, because the Cambrian rocks of the Black Hills region have been recently proved to belong to an age earlier than the Potsdam. The term "refractory" is open to the least objection, in that amalgamation has proved uniformly unsatisfactory in the treatment of this class of ores. It does not, however, serve to exclude those ores of a more basic composition which are of frequent occurrence. For the purposes of this paper, then, the term "refractory siliceous ores" has been adopted as expressive of the most striking features of the ores and as least at variance with the names now in use.

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[a] Trans. Am. Inst. Min. Eng., vol. 27, 1897, pp. 404, 428.

The ores are widely distributed over a broad, irregular belt extending from Yellow Creek on the southeast to Squaw Creek on the northwest. This belt includes five productive areas, which have been severally designated as the Bald Mountain area, Lead area, Yellow Creek area, Garden area, and Squaw Creek area, the last named being little more than a prospect[a] and situated at the junction of Squaw and Spearfish creeks.[b]

The ore is an extremely hard, brittle rock, composed largely of secondary silica and carrying, when unoxidized, pyrite, fluorite, and other accessory minerals. It occurs in flat, banded masses, in which the banding is continuous with the bedding planes of the adjoining strata. These masses possess a regular, channel-like form and follow zones of fracture that vary in their general direction in the different districts, but have a very uniform trend in any single productive area.

These channel-like ore bodies are known as "shoots" and have a width of from a few inches to, in rare instances, 300 feet. The length is in all cases many times greater than the breadth, and in one instance reaches nearly three-fourths of a mile. The vertical dimensions vary from a few inches to a maximum of 18 feet. The average thickness is about 6 feet. The channels generally follow either single zones of fracture, which are parallel to their longer diameters, or broad areas of parallel or intersecting fracture. A series of typical cross sections of these ore shoots may be seen in Pl. XI (p. 214).

The country rock in which the ore occurs is a dolomitic limestone of fine-grained crystalline texture and varying, like the ore, in its degree of oxidation. It is termed "sand rock" by the miners. In its fresh condition it is a dense, gray, crystalline rock showing innumerable small cleavage faces of dolomite and generally interrupted by bands of greenish-black shale of varying width. When oxidized it has a deep-red color, but presents the same glistening facets, while with very advanced alteration it passes into a red, earthy material termed "gouge." Dolomite beds of this character have so far been found to contain ore bodies at two positions in the Cambrian series; the first being immediately over the basal quartzite, from 15 to 25 feet above the Algonkian schists, and known as the "lower contact." The second is from 18 to 30 feet below the *Scolithus*, or so-called "worm-eaten" sandstone that forms the top of the Cambrian series, and is termed the "upper contact." Other beds of dolomite occur at intervening levels and have

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[a] As this paper goes to press the writer is in receipt of a paper by C. C. O'Harra, in which this Squaw Creek area, where the Cleopatra mine is situated, is shown to have become a very important producer since the writer visited the region.

[b] A small additional area in Spruce Gulch has been shown on the map, but the ores here found are so much more basic than the normal siliceous ore and are of such small importance that they are omitted from this discussion.

produced a little ore at some few localities. They have been but little prospected; more extensive exploration may show them to be frequently mineralized.

The beds that form the roof of the ore are generally shales of a more or less impervious character, or not infrequently sills of eruptive rock.

The floor upon which the ore rests is sometimes the basal Cambrian quartzite, but in many cases varying thicknesses of dolomite intervene between it and the ore. In such cases the widest portion of the shoot is directly beneath the impervious rock of the roof, the solutions having spread out and replaced the dolomite to the greatest distance along the under surface of the rock which checked their upward progress. In a few instances the ore lies on a floor of eruptive rock. On the upper contact the floor is either dolomite or shale.

The grade of the ore is different for the separate productive districts. For the main or Bald Mountain area and for the Garden area the average yield is about $17 per ton; for the Lead and Yellow Creek areas it is possibly $45.

The ores are mainly ores of gold, but occasionally carry quite high values in silver.

DETAILED DESCRIPTION.

LITERATURE.

With three exceptions the literature relating to the refractory ores is of a very fragmentary character, such reference as is made to them being only incidental. The first of the three exceptions referred to is a paper by W. B. Devereux,[a] entitled "The occurrence of Gold in the Potsdam Formation, Black Hills, South Dakota." This paper is mainly concerned with the auriferous conglomerates described in the foregoing pages, but includes a brief discussion of these ores, at that time but little developed and less understood. In this paper occurs the following description:

> "* * * Several miles distant gold occurs in the same formation in considerable quantity, and with such characteristics as to justify its being classed as a chemical constituent.
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> "This locality is known as Bald Mountain, and comprises an elevated area of several square miles, through which quite an extensive mineralization has taken place. The same geological features are here met with that I have already described; a base of schists, upon which are typical quartzites, from which the sedimentary character has been almost obliterated by metamorphic action. These are penetrated in every direction by porphyritic dikes, the overflow from which has, in places, formed high peaks. There is generally a small stratum of conglomerate next to the schist, but the sediments were generally quite fine. Through the area mentioned ores of gold and silver are quite common, although I do not know that their treatment has proved to be a financial success. The ores seem to be impregnations, and not confined to veins with well-defined walls. In fact, true vein quartz is rare, and I am not sure

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[a] Trans. Am. Inst. Min. Eng., vol. 10, 1882, pp. 465-475.

that I have seen any, although some of the quartzite would be taken for quartz if examined without a knowledge of its occurrence. The silver occurs as chloride, more rarely native, and is confined to small fissures in the rock. Copper stain is also common. Gold occurs native, but in so fine a state as to be seldom visible. I have noticed it as a brown sponge in cavities in the quartzite, and with no metallic appearance until compressed with a knife, when it immediately assumed the luster and color of gold. These cavities are very common in the quartzite and are generally lined with quartz crystals.

"The ratio of gold to silver is variable, and ranges from a small percentage of the total value to half. Continuous bodies of rich ore seem to be rare, although specimens giving high assays can easily be obtained. From its appearance the sponge gold described should be nearly pure, but I have never been able to test it. At the time of my observations, which was several years ago, the developments through the region were very limited, and I was unable to form conclusive opinions regarding the character of these deposits. Certain facts seemed to be pointed out: First, that the metallic constituents seemed to be segregated along certain strata through which there seemed to have been less resistance to the passage of the mineral solutions; secondly, that in these planes there is a concentration along certain vertical planes, which planes are contacts of the quartzite with porphyry dikes. Almost all of the openings showing ore conform to these two conditions. I have sampled portions of decomposed porphyry which were very rich in silver, and gold or silver seemed to be found in almost every opening made along a certain plane within certain limits. I have also examined these dikes below the contact of the quartzite and the schist, and found them, to a certain extent, lines of mineral segregation. It, therefore, seems doubtful whether the minerals came from below, or were derived by segregation from the sediments themselves. I am inclined to think that both causes were in operation. In one place we found that the lower sedimentary stratum was highly charged with oxide of iron, and that a sample gave over twenty dollars in gold per ton, although it was so fine that no gold could be obtained in the pan, an almost universal characteristic of these ores, and one which bars the use of the simple stamp mill without amalgamating pans for reduction."

In this statement Devereux has embodied two very important facts: First, these ores occur in certain well-defined beds, and, second, they follow definite vertical planes or directions. In so far as he connects these vertical planes or directions with porphyry dikes the evidence does not support his assumption, nor does the ore usually occur in quartzite. Furthermore, the instances in which native gold is found have proved to be very exceptional, and only one or two very doubtful occurrences have come to the observation of the writer.[a] The fact that the ores are difficult to treat has since been thought to be due in part to the combination of the gold with tellurium as well as to its very fine state of division. Chloride of silver has been reported from a very few of the siliceous

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[a] In the Hidden Fortune mine, north of Lead, native gold occurs in great abundance in the ore, but the conditions here may be considered somewhat exceptional, so that the above statement is accurate for all other occurrences.

ore bodies with relatively high silver content, but is an extremely rare constituent of these ores.

The second paper relating to these ore bodies is that by F. R. Carpenter, and is entitled "Ore Deposits of the Black Hills of Dakota."[a] Under the heading "Contact deposits" Carpenter describes the ores as replacements by silica and pyrite of the limy portions of the country rock, which he describes as sandstone or quartzite. He draws attention to the fact that they are in no sense due to the filling of preexisting cavities, and further states that gold is more widely developed in the lower, and silver in the upper, strata of the Cambrian.

The eruptive rocks are considered as of earlier age than the ore deposition. The ores are described as intimately associated with the igneous intrusions to which he considers they owe their origin, and he believes that the refractory ores will be found coextensive with the distribution of the intrusives throughout the Cambrian rocks.

The conclusions of Carpenter in regard to replacement, as well as other of the essential features of this paper, have been confirmed by recent investigation, but certain modifications have been suggested by studies of the writer. The cases in which the siliceous ores are mineralized quartzite are confined to a few localities where the latter rocks contain unusual amounts of carbonate of lime. The majority are undoubtedly mineralized dolomite which, in some cases, contains sufficient quantities of sandy material to be termed a calcareous sandstone, but it is rather important to recognize that the original country rock before mineralization was a limestone, and that the grade of the ore has been lowered in the same proportion that it was contaminated by sandy or shaly material. Some confusion seems to have existed on this point in the minds of most early writers.

As regards the relation of ore bodies to eruptives, it is quite true that they occur only in the vicinity of the latter and are of later introduction, but that the ores are the effect, and the eruptives the cause, has not been demonstrated.

The third and most recent discussion of these ores is in a paper by F. C. Smith,[b] entitled "The Potsdam gold ores of the Black Hills of South Dakota." Parts of this paper have been quoted in full in the following pages.

Professor Smith discusses the geology of the siliceous ores of what he terms the "northern connected district," an area that includes the Bald Mountain area of his paper, but omits the Yellow Creek, Lead, and Garden areas. He then adds a discussion of the ores, of which the following is a short digest:

The Potsdam ores are "thoroughly reorganized sandstones showing, under the microscope, many druses lined with innumerable quartz crystals, and containing

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[a] Trans. Am. Inst. Min. Eng., vol 17, 1889, pp. 582-588.

[b] Ibid., vol. 27, 1897, pp. 420 et seq.

calcite and fluorite." He divides them into blue or unoxidized and red or oxidized ores, giving analyses to prove the origin of the latter from the former, and states that both varieties are "very brittle and hard to break or pulverize." He finds by many careful analyses tellurium and gold and silver in quantities requisite for the formation of tellurides There are two ore-bearing beds or horizons. In discussing the origin he says the "mineralization is undoubtedly referable to the igneous action, which is so strongly marked in their vicinity." This connection he describes in detail as follows: "Wherever mineralization of the Potsdam beds has occurred it can always be traced to a quartz-porphyry or rhyolite dike or 'vertical,' which itself is usually mineralized, stained with oxide of iron, and so much broken and decomposed that its rock character is distinguishable with difficulty." He then further discusses the influence of the intrusives and adds certain conclusions which, as they do not bear directly on the question at issue, are here omitted.

Professor Smith's descriptions and conclusions as to the character of the ore have been fully borne out by later investigation, and it seems probable that the refractory character of the ores is in part due, as he supposes, to the combination of the gold with tellurium. The ores are not, however, "thoroughly reorganized sandstones" except in so far as the replaced dolomite has shown locally a slightly sandy character. His statement as to the relation of ores to the eruptives is also incorrect, since the so-called "verticals" are fractures, not decomposed dikes.

An additional discussion of these ores was published by the writer[a] just prior to the year in which the fieldwork for this paper was completed, but as the results there set forth are largely embodied in this paper they will not be further discussed.

HISTORY AND DEVELOPMENT.

The following brief history of the ores is found in Professor Smith's paper[b] and is quoted in full:

"The history of the Potsdam ores commences in 1877, when Mr. A. J. Smith, of Portland, S. Dak., located the Empire mine on Green Mountain and later the Trojan, Perseverance, and Indispensable in the same vicinity. In 1879 the first engine was erected to supply power for the treatment of these ores. With it an arrastre was run upon ores from the Empire mine averaging about $35 per ton. The saving in precious metals was little or nothing, and the attempt was discontinued after about two months. In 1880 the Portland Mining Company, owning the Portland, Gustavus, and Pilgrim mining claims, built a mill (which still stands idle near the old town of Portland) for the treatment of these ores by pan amalgamation; later this company purchased the Empire, Trojan, Indispensable, Perseverance, Folger, and Olive

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[a] Ann New York Acad Sci vol 12, pp 297–311

[b] Trans Am Inst Min Eng, vol 27, pp 420–422

claims. Pan amalgamation saved about 50 per cent of the silver and 30 per cent of the gold, and various other processes, such as "free milling," kiln roasting, chlorination, and cyanide lixiviation were tried without success. In 1883 the Welcome Mining Company passed through a similar history of unfortunate metallurgical experiment upon their property near the head of Fantail Gulch. In 1886 the Buxton mill was built by the Buxton Mining Company, and experiments made there by Mr. O. P. Ankeny, by the use of bromine, seemed to have stopped just short of success, probably on account of disadvantages which at the present date would not surround the experiment. About this time the siliceous ores were successfully treated by the Plattner process in the metallurgical department of the School of Mines. In 1889 the Golden Reward Gold Mining Company erected a plant in Deadwood for the treatment of the Potsdam ores by barrel chlorination, commencing in April, 1891, with a capacity of 50 tons per day. In 1890 the Deadwood and Delaware Smelting Company built the small experimental smelting plant in Deadwood which has since grown so largely. Two years later, or in 1892, a small cyanide plant was erected in Deadwood by the Black Hills Gold and Extraction Company, and in November, 1895, the Kildonan Milling Company started chlorination works at Pluma, S. Dak. (a short distance from Deadwood), with a capacity of about 75 tons per day.

"During the time from the first disastrous attempts at the treatment of the Potsdam ores until more skillful experiment had firmly established the Deadwood and Delaware and the Golden Reward plants, although considerable amounts of ore were shipped outside of the Black Hills for treatment, the fact that ores of less value than about $30 per ton could not be mined and shipped with any profit, together with a superstitious feeling that there was something "uncanny" about these ores and that they could not be treated successfully, prevented an active development of the Potsdam ore bodies. Only within the last three years have the old conditions been changed, and miners can now generally obtain a profit from ores carrying $15 per ton. Naturally the earlier mines in the Potsdam ore bodies were located where the Potsdam rocks were easiest of attack, in the vicinity of Green and Bald mountains and to the east of Terrys Peak in Nevada, Fantail, and Whitetail gulches. In these localities the three large companies which handle the Potsdam ores (the Deadwood and Delaware, Golden Reward, and Horseshoe) own and operate a large number of very valuable mines, and smaller companies and individual owners hold the remainder."

PRODUCTION.

The obtainable data on the production of these ores are of the most meager description. The report of the State mine inspector for the year 1897 gives the following:

Production of siliceous ore in northern Black Hills

Golden Reward	$682,205.32
Deadwood and Delaware	504,000.00
Horseshoe	304,500.00
Bonanza	134,561.24
Wasp No. 2	182,845.12

Dividend	$63,017 54
Clinton and Ashland	60,380.09
Carrol Group	50,000.00
Harrison	41,106.80
Little Blue	52,000 00
Wasp Mining Company	4,500.00
Wasp No. 4	1,200 00
Rua	20,000.00
Balmoral	16,821.38
Buxton	10,997.71
Eva H	12,000 00
Yellow Creek Gold Mining Company	24,152 38
Total	2,164,287 58

As the total gold output of the Black Hills for the same year is given as $5,631,237, it will be seen that the siliceous ore production for that year was about two-thirds that of the Algonkian ores. Since this report it has steadily increased.

CHARACTER AND POSITION OF THE BEDS IN WHICH THE ORE OCCURS.

PHYSICAL CHARACTER

The rock in which the refractory siliceous ore occurs is a crystalline magnesian limestone or dolomite. It forms beds of variable thickness at different positions in the Cambrian series, and is known among the miners as "sand rock."

Macroscopic appearance.—In its fresh and completely unaltered condition it is a dense, massive rock of light bluish-gray color, consisting chiefly of an aggregate of small glistening grains of lime-magnesium carbonate, among which are scattered minute masses or crystals of pyrite. Little irregular flecks of glauconite often give it a greenish tinge, but they are rarely present in sufficient abundance to become a conspicuous feature. Alternating with the beds of this dense, marble-like rock is dark, greenish-black shale, which is arranged sometimes in even, parallel bands, and sometimes in extremely irregular or distorted patches. In some places these shale bands are so nearly absent that the rock resembles a fine-grained homogeneous marble with thin lines or traces of shale in just sufficient amount to bring out the stratified nature of the rock. In other cases the shale beds are much thicker and not infrequently occur in such abundance that the strata partake more of the nature of highly dolomitic shale than of crystalline limestone. All gradations exist between these two extremes, but the prevailing occurrence is where the dolomitic beds are in the preponderance. The shale bands are then extremely thin and at varying distances from one another. They often exhibit a very marked cross bedding and bring out clearly the sedimentary origin of the rock. Regularity of banding is, however, rarely continuous, for it is interrupted by crushed and contorted layers, by irregularly distributed little faults, and often by a confused brecciated structure. These brecciated structures become at times very pronounced, so that the stratification is completely obliterated, and the broken fragments are often rounded in such a way as to give to the rock the appearance of a conglomerate.

Microscopic appearance.—Under the microscope the ore-bearing rock, or dolomite, is seen to be of two different varieties: (1) An aggregate of interlocking anhedra[a] of dolomite, none of them possessing crystalline boundaries; and (2) an aggregate composed of rhombs of dolomite, all of them complete crystal individuals.

Dolomite of the first variety is composed of an aggregate of anhedra of dolomite impinging upon one another with extremely irregular boundaries. Among these are scattered irregular rounded grains of quartz, masses or crystals of pyrite in the unoxidized varieties, minute specks of magnetite, irregular patches of green glauconite, and an occasional mass of calcite. The main body of the rock is made up of the dolomite. It clearly shows rhombohedral cleavage, but never, even when strained, is there twin lamellation. Calcite when present can be readily distinguished from it by this means. The rounded grains of quartz show all the attributes of detrital material, and probably remain as they were prior to the marbleization of the rock. They sometimes occur in great abundance. In the specimen taken from the Two Johns mine, they are segregated into definite layers where they formed almost 50 per cent of the rock. As a rule they are, however, much less frequent in their occurrence and at times are completely absent. The magnetite occurs in such exceedingly minute masses that it can with difficulty be recognized. Glauconite is present generally in a small quantity. It forms irregularly rounded masses of considerable size, showing the usual aggregate polarization, and almost invariably in a very fresh condition. In one or two of the most highly oxidized specimens it shows signs of decomposition. The pyrite is absent from oxidized specimens, in which the iron content is a limonite distributed along interstices between individuals of carbonate and along the cleavage cracks of the same mineral. The aggregate amount of iron is probably insignificant, although the rock is often very deeply stained with iron oxide. In some specimens, notably those from beds above the De Smet cut, and from the Belle Eldridge mine in Spruce Gulch, the microscope reveals fragments of shells and small irregular plates perforated with many minute holes. The latter are probably some form of Foraminifera and their

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[a] Anhedron is here used to designate a mineral grain or individual which, while it is crystalline in its internal structure, so that it polarizes light, etc., has been prevented from developing crystal faces by the presence of contiguous grains of the same or other minerals. It simply fills up the irregular space between the other mineral grains.

presence indicates that the rock originally consisted of the remains of organisms, the greater part of which have been completely obliterated by subsequent marbleization.

A micro-photograph of this rock is shown in Pl. X, *A*, facing page 214.

The second variety of structure observed in the dolomite is that where the rock consists of an aggregate of automorphic crystals[a] of dolomite. Inclusions and staining by oxide of iron has produced dark bands in these crystals, that give to them a marked zonal appearance and bring out distinctly the thoroughly crystalline character of the rock. These rhombs are sometimes exceedingly small and of uniform size, but in other instances irregular bands of larger individuals are distributed through the rock. (See Pl. X, *B*, p. 214.) In other respects this variety shows no essential differences from that first described.

The first variety of dolomite or "sand rock" is more common on the lower contact, the second on the upper. The two, however, grade into each other and are not to be distinguished without the aid of the microscope.

Alteration.—The alteration of the dolomite produces a progressive series of changes in the appearance and condition of the rock. The first mineral attacked is the pyrite, which becomes rapidly oxidized. The limestone then becomes stained with oxide of iron, so that it changes to a deep Venetian red, or yellowish brown. The flashing cleavage faces remain unaltered, and, together with the red color and peculiar even texture, give the rock a very peculiar and easily recognized appearance. The black shale bands become stained to dull red by iron oxides, and where very impervious frequently exchange their black color for a light gray. The glauconite does not seem to have been much affected by alteration, being frequently found in the most decomposed specimens. It is improbable that all of the iron oxide that stains this rock arises from the decomposition of the pyrite; much of it has probably been introduced by oxidizing waters that have seeped downward from the beds above.

The next step in the oxidation of the rock after the pyrite has been removed and the rock stained red is the gradual solution of a portion of the carbonates. By this means the rock loses its massive structure and passes into a red or yellow earthy material composed of disintegrated fragments of lime and magnesium carbonate, limonite, included sand grains, and whatever clay originally existed in the rock. This completely decomposed material is known to the miners as "gouge," and is especially well developed on the edges of ore bodies, even when the ore and wall rock are comparatively unoxidized. One of the most noticeable features of this gouge-like alteration is the prominence given by it to the banding of the rock. The dolomite bands become darker by reason of the introduction of iron oxide, but the shale bands, on account of their impervious

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[a] Crystalline mineral grains which have fully developed crystal faces are termed automorphic.

nature, retain the greater portion of their original material and are therefore of lighter color. Thus with the increasing alteration the banding of the rock has been rendered more pronounced, and it is often supposed that red ores come in shales and blue ores in the limestone. Gradual transitions, however, between the gouge and the original blue, unaltered rock are frequently observable, no single step in the alteration being absent. At times the red gouge has preserved the structure of the rock from which it was derived, so that angular fragments will present the appearance of a hard, massive limestone, while in reality a touch will serve to cause them to crumble into a loose mass of soft earth.

CHEMICAL COMPOSITION.

An analysis was made by Mr. W. F. Hillebrand of a specimen of the blue unaltered dolomite taken from the long crosscut of the Tornado mine known as the "Bx" crosscut. The portion analyzed was taken from a layer free from shale bands, and showed dolomite, calcite, quartz, pyrite, and glauconite, with a few minute specks of magnetite. After treatment with hydrochloric and sulphuric acids, the residue of quartz grains, pyrite, and magnetite was further examined under the microscope. The quartz grains were rounded and without doubt of detrital origin. The pyrite was in irregular masses and occasional crystals, and the magnetite in such an extremely fine state of division that it merely imparted to the residue a slight grayish tinge, and could only be recognized as such by means of the magnet.

The analysis gave the following results:

Analysis of unaltered dolomite from Tornado mine.

	Per cent.
SiO_2	5.74
Al_2O_3	2.02
Fe_2O_3	.64
FeO	6.47
FeS_2	.69
MnO	.97
MgO	14.75
CaO	26.81
Na_2O	.07
K_2O	.53
H_2O—105°C	.34
H_2O+105°C	.67
P_2O_5	.08
CO_2	40.11
Total	99.89

It has not been possible to calculate the exact mineral composition on account of the variable composition of the glauconite, but it will at once appear that the proportion of carbonates present is much in excess of all other minerals. If the lime, magnesia, ferrous oxide, and manganese oxide be calculated so as to combine with total carbonic acid present, the aggregate amount of carbonates represents about 87 per cent of the rock. These elements probably do not exist as separate mineral species, but occur as isomorphous mixtures, the iron and manganese replacing a part of the calcium and magnesium of the normal dolomite. Some distinctive calcite does, however, occur; but the amount is small. The formula would probably be about as follows: $CaMg(MnFe)(CO)_3$, where small quantities of Mn and Fe occur in the dolomite molecule.

The alumina is too high for glauconite of normal composition, and indicates that a small amount of kaolin is present. This would consume a portion of the silica, potash, and combined water. The remainder of the alumina, potash, and combined water, part of the silica, considerable magnesia, and all of the soda and phosphorus are probably contained in the glauconite. The balance of the silica is present as sand grains.

The percentage of glauconite and shaly material increases with the increase in the quantity of shale bands in the rock, and as they always persist unaltered in the ores, they are to be regarded as impurities in the normal ore-bearing rock.

GEOLOGICAL POSITION OF ORE-BEARING BEDS.

In the Cambrian group these dolomite beds most frequently carry ore at two levels, which are locally known as the "lower" and "upper" contacts, although it is probable that other beds will be found within the intervening portion of the series, but such have not yet been carefully sought.

Lower contact.—The lower beds lie generally directly upon the basal quartzite of the Cambrian and are from 6 to 30 feet thick. The bands of impervious blue shale which interrupt the continuity of this rock vary greatly in thickness and occur at intervals which increase or diminish without regularity. The result is that if traced for any great distance the dolomite beds show a lenticular form, passing from a thick mass into thinner and thinner bands until they finally disappear in the surrounding shales. Frequently such lenticular beds are arranged so that one passes laterally beneath the next succeeding one above, but dwindles to nothing, while the higher or lower bed continues. It therefore happens that the lower beds vary in their exact geological position; at some places they lie directly on the quartzite and at others are some distance above it, the intervening space being occupied by thin alternating beds of shale and impure limestone. The beds of dolomite and their intercalated shale are in some places overlain by a series of extremely impervious blue shales, which break with a triangular cleavage and never show any indication of mineralization. At times the limestone becomes so thin that the blue shales lie but 5 or 6 feet above the basal quartzite; generally the distance is much greater. It very rarely happens that shale horizons of this extremely impervious character lie directly on the quartzite. Although the aggregate thickness of these ore-bearing beds is sometimes as much as 30 feet, their continuity is always interrupted by shale beds, often of considerable thickness, and it is usually such a bed of shale that forms the roof of the ore bodies.

The dolomite beds that lie upon the lower quartzite are remarkably uniform in their distribution. They occur in Garden, Ruby Basin, Portland, Squaw Creek, Lead, Yellow Creek, and recently a drill hole has revealed them to a thickness of 12 feet at the base of the Cambrian that underlies the Carboniferous limestone of the Ragged Top plateau. On the west of Spearfish Canyon, in the vicinity of the porphyry masses known as the "needles," a tunnel has revealed the same dolomite series. In the Two Bit district, however, in the Detroit and Deadwood shaft, this rock is absent, and it probably does not occur in the region to the east and southeast of Deadwood. Its distribution in a direction westward from Lead is, however, very uniform.

Upper contact.—The position of the upper beds of dolomite is about 12 to 18 feet below the *Scolithus* sandstone that lies near the top of the Cambrian series.

There are in most of the mines on the upper contact two beds of this dolomite separated by 3 to 4 feet of shales. In many instances—such as the Mark Twain and the Burlington mine, near Portland—the ore that occurred in the lower of these two beds was completely removed before the parting of shales had been broken through, and the ore of the upper bed discovered. It is stated that in the South Dakota mine, at the head of Annie Creek, as many as five or six separate beds of ore replacing blankets of dolomite, 1 foot in thickness, occurred. Two blankets of ore also occurred in the Dividend mine, and in a portion of the Mark Twain mine the same duplication occurs. Occasionally shales which lie between beds of dolomite have been slightly silicified and carry small quantities of gold. The large proportion of clayey material which they contain has, however, prevented their complete mineralization, and it is only in the purer and more massive bands of limestone that workable ore bodies occur.

The dolomite beds of the upper contact, as exposed at Portland, have been discovered in the region of Ruby Basin and in the headwaters of Annie Creek, but their occurrence at other localities has not been determined. Intermediate beds of dolomite—such as that seen in the Belle Eldridge mine, in Spruce Gulch—are mentioned by Mr. Tower as occurring in the vicinity of Galena and Strawberry Gulch, but their exact position is not definitely determined, and that these intermediate beds do not carry ore when present in mineralized localities has not been proved.

The two contacts most commonly known have been developed because they have been the most easily accessible. The exploitation of the lower contact especially has been extremely easy on account of the almost invariable occurrence of that series of dolomite beds directly over the quartzite, thus permitting the use of the latter rock as a basis for exploration. Indeed, so much has this occurrence on or close to the quartzite been emphasized that it has become the dogma among miners to "sink to quartzite" before prospecting for ore. The ore-bearing beds of the upper contact near Portland and the ore occurring in them outcrop all around Green Mountain and along the railroad, so that ore bodies on that contact were easily accessible. The existence of ore shoots in beds lying between these horizons is not only possible, but probable, and future prospecting may reveal them.

ORE BODIES.

FORM AND SIZE.

The ore occurs, as stated above, as flat, more or less banded masses, which have a channel-like form and are parallel or nearly parallel to the bedding planes of the strata in which they are found. Such bodies are locally known as "shoots," a term which it will be convenient to use throughout this paper for any single body of refractory siliceous ore of whatever form or size.

Viewed in horizontal projection the larger number of shoots shows a long lenticular form, slightly broader at the center and becoming narrower at either end. As shoots are seldom mined to their extremities, these relations can not be fully appreciated from the map (Pl. IX, p. 214). Broad shoots are more irregular in shape than the smaller bodies, and, as they are in reality formed by the junction of intersecting or parallel shoots of smaller size, have no absolutely constant form (Pl. XIII, p. 214). They are, however, generally longer than broad. Viewed in cross section, there is a complete gradation from a narrow lenticular shape with longer axis in a vertical position to a great flat bed remarkably conformable to the bedding planes of the strata and with its width many times greater than its thickness. Between these two extremes shoots possess variable and often very irregular forms. Some of these are shown in Pl. XI (p. 214), which gives a series of cross sections and illustrates the gradation between large and small ore shoots.

Only where ore bodies are very wide is there an absolute conformity to the bedding planes of the strata, and then only in the roof of the ore. The lower boundaries generally cross the strata at an angle and extend downward a great distance along the fractures; above the ore usually terminates against a bed of shales that seems to have been a barrier to the farther upward passage of mineralizing waters. At times when shoots are interrupted by many shale beds they have the form shown in Pl. XI, *G* (p. 214).

The length of the shoots varies from a few feet to about four-fifths of a mile. The Tornado-Mogul shoot, which is probably the largest single body of refractory siliceous ore yet mined, had a total length of 4,153 feet. The Bottleson shoot, including that portion that extends into the Alpha-Plutus mine, was 3,290 feet in total length. The large No. 1 shoot of the Union mine, exclusive of its probable continuation in the Ruby Bell, had been mined when visited to a length of 1,750 feet, and was not then completely worked out. The Ross Hannibal shoot was 1,500 feet long; the Steward, 1,160; the Boscobel, 1,050, and the Double Standard, 900. On the upper contact the shoots of the Mark Twain and Empire State mines, which practically constitute a single ore body, show a total length of 2,000 feet. Shoots having a length of from 600 to 800 feet are of frequent occurrence, while those between 600 and 100 feet constitute perhaps one-half of the total number of shoots mined. In general shoots having a length less than 100 feet are not very often encountered, and when found are often too narrow and poor to pay for mining. This is especially true in the mines of the Bald Mountain area where the ore is not of very high grade. In the Yellow Creek and Lead areas the ore is higher in gold content and occurs in much smaller bodies, so that shoots of very small size are often workable.

In width shoots vary from a narrow film of silica lining the sides of an almost imperceptible crevice to great flat bodies 300 feet or more in width. The widest shoot mined is that of the Golden Reward mine on the south bank of Nevada Gulch, which measures 340 feet at the broadest point. The Tornado at its widest point is 180 feet. Shoots 100 feet in width are of quite frequent occurrence, and those from 100 feet down to 4 or 5 feet are mined in many places. Perhaps, however, the most usual width of ore shoot throughout the region is from 5 to 20 feet, such occurring with greater frequency than any of the other widths cited. The width of a shoot varies a little from point to point, and in many cases is greatest about midway of its course, gradually diminishing toward the extremities. The Tornado-Mogul shoot is 180 feet wide slightly north of the central point, but it narrows to 10 feet at its northern outcrop and pinches out entirely at the south end. Very wide shoots like the Golden Reward are generally formed by the convergence of many smaller ore bodies having slightly discordant trends; thus the total width is diminished in any particular direction by the introduction of wedge-shaped areas of unmineralized rock.

In general, there is no constant relation between length and breadth. Except in a few cases where very wide shoots, like the Golden Reward and the inclined shoot of the Little Bonanza, are nearly as broad as they are long, the length is many times greater than the breadth. The longest shoots are sometimes broad, as in the case of the Tornado-Mogul, but there are many cases like the Boscobel, where a shoot 1,450 feet long never shows a greater width than 10 feet.

The vertical dimensions are the least variable, because the ore deposition being due to the replacement of certain more soluble sedimentary beds is limited only by the thickness of those beds. Consequently the thickness for narrow ore bodies is as great as for wide ones, at least in the same locality.[a] Where the ore-bearing beds are very thick the ore is likewise thick. From 5 to 10 feet is a conservative estimate for the Bald Mountain area, as also for the Garden area. In the Portland district the thickness of the ore is not often more than 3 feet and often ranges between that and 1 foot. It rarely happens that the ore in a shoot of any considerable size is continuous from the floor to the roof, for it is almost always interrupted by partings of unmineralized shale. These are termed "waste" by the miners and have to be carefully removed by sorting. Where such "waste" beds are thicker than the ore there are practically two ore shoots or blankets one above the other. The thickness of a shoot often diminishes at the rims, where the ore thins to a feather edge. Other cases occur where the transition from ore to country rock is such that the shoot retains its full thickness to the rim.

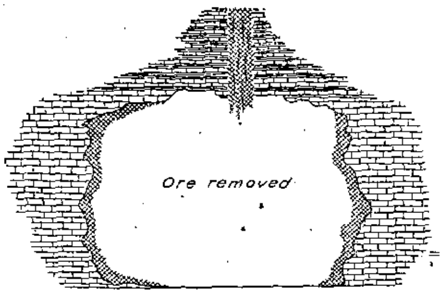

FIG. 13.—Sketch of "vertical" as seen in cross section, showing the manner in which it projects from the surrounding country rock on account of the resistant character imparted to the adjoining material by silicification.

FRACTURES.

In all of the stopes from which the ore has been completely excavated discolored seams may be observed. These are generally quite conspicuous, both on account of their slightly iron-stained appearance and on account of the resistant character of the material of which they are composed, the latter feature having frequently caused them to project from the softer, unmineralized country rock. They may be most readily observed in the beds overlying the ore, as these are of slightly lighter color and of a more shaly character than those in which the ore itself occurs, but if carefully followed to the side or end of the stope may be traced downward into the underlying quartzite, shale or dolomite, whenever mining operations have revealed the rock below the ore. These seams are known to the miners as "verticals" (Pl. XII, p. 214).

In a "vertical" there are two features to be distinguished: 1. The original fracture. 2. The mineralization along or proceeding from that fracture.

The original fracture is a result of rupture due to strains in the country rock. It may have been a simple crack with no perceptible open space between

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[a] The exception is where narrow and extremely high ore bodies are formed along very open fractures, as in the Penobscot mine (see Pl. XI, *C*, p. 214).

the walls or a crevice an inch or more in width. Secondly, as a result of mineralization the fracture is often filled by siliceous deposits and sometimes stands out as a small ridge in softer material, or it may be lined with quartz crystals and not completely filled. Often it is not clearly distinguishable in the mass of the ore. As a result of the replacement of the country rock on either side of the crevice a sheet of hard siliceous rock is formed which may extend for considerable distances on either side of a fracture. If extensive it forms an ore shoot; if slight, a "vertical." This vertical is often confused with the fracture, but it is important not to confound the two. The fracture admits the solutions and the ore body is formed by them.

The original fractures are either simple or composite.

The simple fractures have slight displacement along surfaces which are sometimes perfect planes, but more frequently are slightly warped or curved surfaces. No unevenness or brecciation occurs along fractures of this type, and verticals which result from their mineralization are generally extremely narrow and regular.

A composite fracture is caused by the intersection of many small, irregular fractures running in all planes and at all angles to one another, and constituting a zone of fracture. This can not be described as a brecciated zone, because fragments have not been perceptibly moved from their respective positions.

Simple fractures when followed to the limits of the ore, where their traces can be distinguished in the walls of the stopes, show that they are planes of movement. The faulting that has taken place is in the majority of cases extremely small, but is almost always clearly discernible. It generally averages from one-quarter of one inch to 6 inches. The differential movement that takes place along such fractures may be both vertical and horizontal. If the movement is vertical it is usually shown by a very pronounced drag in the extremities of the dislocated strata; if horizontal it is indicated by horizontal striations in the underlying quartzite.

The planes of movement of these faults are, as is usual in fault planes, curving or slightly warped surfaces. They are, further, faults of but slight displacement; faults of larger displacement—in one instance of 300 feet—occur, but show no evidence of mineralization and are probably of later date.

All gradations from the simple to the composite type exist. A single and simple fracture rarely continues for any distance as such. In many ore shoots a single fissure, though showing a very constant direction, may change into a composite fracture and still farther on split into a large number of fissures not quite parallel, so that by gradual divergences and convergences they form an interlacing network in the roof of a stope. At times the vertical, which has resulted from the mineralization of a series of parallel fractures, occupies the entire roof of the stope, the space between the individual fractures having become more or less silicified. Simple fractures are generally vertical, or nearly so.

VERTICAL EXTENT OF FRACTURES.

The fractures sometimes extend into the roof overlying the ore, and in all instances where it was possible to make observations, could be traced into the underlying beds. In a few cases it was possible to trace their continuations into the Algonkian rocks below.

In the Mogul mine a drift was run into the slates directly beneath the ore body itself. Evidences of silicification can be detected in the phyllites of the Algonkian, showing that the mineralization extended into the rocks underlying the Cambrian, but where the Algonkian rocks are quartzite, or like insoluble rocks, little or no secondary replacement can be observed.

In the Big Missouri mine the ore-bearing beds lap over into direct contact with the Algonkian, and verticals can be seen passing into the schists which underlie the ore.

In the Hawkeye-Pluma mine verticals from 3 to 4 inches in thickness, consisting of red-stained silicified phyllites, and showing many drusy cavities, extend many feet below the Cambrian into the Algonkian. Siliceous verticals were also detected in the Dividend mine, near Portland, passing from the Cambrian rocks into the Algonkian. It seems, then, very probable that these fractures extended into the Algonkian underlying the Cambrian quartzite. It is to be observed that the Algonkian rocks are not generally composed of soluble nor easily replaced material, so that only when the fractures pass into soft white micaceous rocks do silicified bands become prominent. Moreover, the vertical position of the Algonkian lamination makes it difficult to distinguish banding due to secondary alteration from that characteristic of the original rock.

The upward extent of the fractures seems to be conditioned by the rocks through which they pass. That they extend at times almost, if not quite, through the Cambrian series is rendered probable by their occurrence in those ore bodies which are on the upper contact. This is at least 250 feet above the base of the Cambrian. Again, the fractures which occur in the Carboniferous limestone, both in the lead-silver district of Carbonate and in the vicinity of Ragged Top Mountain, may be the upward continuations of fractures in the Cambrian below. It is not known how much farther they extended into the series that has been eroded away. On the other hand, there are many instances in which the fractures do not pass through the rocks immediately overlying the lower contact ore bodies. In the Ruby Bell mine verticals, or fractures, were observed in the ore; that is, displacements along definite lines or offsets in the banding of the ore, which did not extend into the shales overlying the ore. In those stopes, of course, where the ore had been mined out, verticals that did not extend beyond the ore-bearing beds could not be seen, as the material in which they occurred had been removed. Thus the roof of the greater part of the Ross-Hannibal mine is of a smooth, even shale, showing only a few fractures, and these at great distances from one another. Many of the wider and more extensive ore bodies occurring at Portland show the same phenomenon. In some ore bodies of very considerable size no fractures of any kind can be observed, and it is difficult at first to account for the occurrence of the ore body. In such instances, however, it may frequently be noticed, where ore has been left in the mine, that the banding shows slight dislocations along vertical planes.

It will thus be seen that while the fractures may generally be shown to extend down into the Algonkian, their upward continuation is somewhat variable; they die out in less massive beds where movement has been productive of plastic flow rather than fracture, or where the shattering forces have been stronger they extend for greater distances upward, and probably frequently reach the massive limestones of the Carboniferous.

AMOUNT OF OPENING OF FRACTURES.

The amount to which the opposite walls of fractures have been removed from one another is variable. Openings are either original or have been secondarily produced after the mineralization of a fracture. Primary openings are almost always extremely narrow, thread-like crevices, the actual opening between the opposite walls being generally less than one sixty-fourth of an inch. There are, however, a number of instances in which it is as much as one-eighth to one-fourth of one inch and in a few cases even greater. Thus in the Ben Hur mine a fracture passes from the ore-bearing beds into porphyry and in the latter rock shows an opening of from 2 to 3 inches. The interspace is filled with large crystals of quartz and a good deal of secondary silica. In the Golden Reward mine, where fractures pass into porphyry, the space between adjacent walls is as much as one-fourth inch.

In the Alpha-Plutus mine many of the fractures show considerable openings—sometimes as much as one-half inch in width, and when a fracture showing an opening of this size is composite, or composed of many fissures occupying the space of a foot or more in width, the aggregate amount of opening may be very great. Such instances as these are, however, rare, and open spaces have seldom attained any considerable size. Innumerable instances might be cited where the walls are so closely pressed together that only capillary spaces remain. As a general rule, those fractures that are to be seen in large, flat ore bodies are much smaller and tighter than those in long narrow shoots.

DIRECTION OF FRACTURES.

Fractures are generally arranged in parallel groups, each group following a single direction with comparatively little divergence. Such groups may be termed fracture systems. Two or more such systems may be distinguished in all of the productive areas of siliceous ores. Some systems show great persistence and are heavily mineralized; these correspond in direction to the trend of the greater number of ore bodies, while others are comparatively insignificant, and do not seem to have been productive of ore bodies of any size. Fractures of the first variety have been termed "major" fractures; those of the second, "minor" fractures.

GROUPING OF FRACTURES.

The mineralized fractures are divided up into separate and distinct groups, which correspond closely to the different productive areas of siliceous ore. These groups are separated from one another by intervening areas in which, as far as known, mineralized fractures do not occur. In any one group there are present two or more systems of well-defined fracture which preserve directions that are constant within the limits of that group, but different from those of the neighboring group.

The spacing of the fractures within any one group is generally without regularity. A single group usually shows all gradations from a spacing so close that the individual fractures can hardly be distinguished as such, to one so broad that an unmineralized area of from 400 to 500 feet intervenes between a fracture and its nearest neighbor.

In some of the groups of fracture there is a close relationship between the fractures and the structure of the Cambrian rocks. Thus in some mines ore shoots occur upon the crests of low anticlinal ridges, and the fractures from which they have originated are strongly developed, while in the shallow synclines between them mineralized fractures do not occur.

There are five important groups of fractures, two in the Bald Mountain area, and one each in the Garden, Yellow Creek, and Lead areas.

The fractures in the Bald Mountain area constitute two groups occurring in the vicinity of Ruby Basin and Portland.

In the Ruby Basin district there are two systems of major fracture: One has a direction ranging from N. 15° W. to north-south. The prevailing and strongest fissures of this system are N. 12° W., and are followed by the long E shoot, the Big shoots of the Tornado mine, the Bottleson shoot, and many other shoots of considerable size. The other direction of major fracture is from N. 25° E. to N. 30° E. Fractures belonging to this system may vary 5° on the one side or other of these directions. Minor fractures run N. 30° to 50° W. and occasionally N. 65° E. Other fractures of minor character occur, but they are confined to extremely broad stopes where the network of very small fractures is so intricate that there is no predominant direction. In the Bottleson shoot and in the St. Louis ore body there are other major fractures which trend N. 5° E. In the group of mines west of the 300-foot fault, designated the Boscobel-Welcome group, the fractures follow the same general directions, but vary possibly within wider limits than those of the Alpha-Plutus-Mogul group just discussed.

In the Portland district the prevailing direction of the major fractures and the resultant trend of the ore bodies is between N. 20° E. to N. 45° E., the most constant direction being about N. 35° E. Minor fractures trend north-south, N. 50°–55° E., N. 60° E., N. 80°–86° E., N. 13° E., N. 30° E., and in rare instances N. 35° W. Hence the prevailing trend is strongly toward the northeast.

In the Garden area 5 general systems are important. These run N. 30° E., N. 40°–45° E., N. 55°–57° E., N. 60°–65° E., and N. 85° E. The number of fractures following the other directions is very much less and they may, therefore, be regarded as comparatively unimportant in the part that they have played in the production of ore bodies.

In the mines of the Yellow Creek and Lead areas the Cambrian rocks are so completely weathered that the accurate determination of fractures apart from ore bodies was not attempted. The major fractures here, as elsewhere, follow in general the direction of the longer diameters of the ore shoots, but even these are somewhat small and disconnected, so that it is difficult to settle upon their prevailing direction. Presumably, however, in Yellow Creek their directions are N. 12° W., N. 60° to 80° E., N. 33° to 40° E., and north to N. 3° E. In the vicinity of Lead, so far as could be ascertained, fractures follow with considerable constancy the strike of the lamination of the underlying Algonkian schists—that is, N. 25° to 30° W. Other systems of fracture probably exist, but were not detected.

INTERSECTION OF FRACTURES.

Intersections of fractures occur both in vertical and in horizontal planes. Vertical intersections are comparatively rare, because they can occur only when fractures exhibit pronounced dips, and such are infrequent. An intersection of this character occurs in the western workings of the Mogul mine, and an ore body of considerable size is found at the junction of the fissures. No displacement was observed. Another place where an intersection of two composite fractures in a vertical plane was observed is in the "Double Standard" mine. No displacement occurs at this intersection.

At intersections in a horizontal plane displacements are sometimes observed, but are frequently absent. In the big shoot of the Tornado mine, on the west side opposite the Tornado shaft, a small fracture trending N. 40° E. can be seen faulting from its direct course a large ore-bearing vertical running directly north and south.

In the Clinton mine, near Portland, two small parallel fractures running N. 20° E. are intersected by a large ore-bearing vertical striking N. 65° E., and the two small fractures are displaced for a distance of 8 inches.

In the north end of the "A" shoot of the Tornado mine a strong manifold fracture, trending N. 15° E., which had persistently formed a large ore body from 600 to 800 feet, is displaced 3 to 4 inches to the west on the north side by a minor vertical trending N. 30° W.

In the Donelson mine, in Yellow Creek, an east-west vertical terminates against one running directly north and south, and can not be observed at all on the other side. A few other instances may be cited where intersections of fractures are accompanied by slight displacement, but it is much more usual for intersections to be without appreciable dislocation. When fractures intersect at small angles it is in most cases difficult to observe any intersections at all, because they curve into one another, and so many auxiliary crevices are developed connecting those running in one direction with those running in the other that it would be difficult to say whether the fractures had intersected one another or simply coalesced. Such intersections become more confusing when the fractures are of a manifold and composite character.

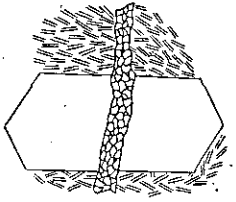

FIG. 14.—Microdrawing of fissure in decomposed trachytoid phonolite, showing character of "vertical" after passing into the phonolite adjoining the ore. From a large dike on the west side of the Tornado ore body.

RELATION OF FRACTURES TO ERUPTIVE ROCKS.

Evidence as to the relative age of fractures and eruptive rocks is conflicting. Fractures younger than eruptive rocks were observed at the places mentioned below.

In the south end of the Golden Reward mine an ore-bearing fracture passes directly from the limestone and overlying Cambrian, where it had been productive of a very considerable ore body, into a sloping floor of phonolite below. In this rock it appears as a number of closely spaced, parallel fissures one sixty-fourth to one-fourth of an inch in width, which are filled with secondary silica and often show narrow, vug-like cavities at the center and parallel with the walls of the fissure. A similar passage of a vertical into a sheet of phonolite occurs in the Mark Twain mine, near Portland, also in the south end of the Tornado mine (see fig. 14). In the No. 3 shoot of the Union mine the phonolite which overlies the ore is seamed with intersecting fissures carrying secondary silica. In the Retriever mine, on the divide between Nevada and Fantail gulches, the ore lies between a cap of rhyolite and a floor of quartzite, and the feeding verticals can be traced into the porphyry cap where their iron-stained appearance has rendered them extremely prominent. In the Mail and Express mine, in Sheeptail gulch, intersecting verticals may be traced from the ore into the rhyolite roof, but become extremely fine and thread-like in the latter rock.

In the Mogul mine fractures extend from the ore into the benching dike that forms the west wall of the ore body. They do not occur in that rock with very great frequency, however, and considering the number of fractures that occur in the surrounding country rock it is the more remarkable that they are not more numerous in these larger porphyry masses.

In the Ben Hur mine a fracture in porphyry about 2 to 3 inches wide carries rich ore for a considerable distance and then passes from the porphyry downward into the dolomite, which here lies immediately above the Algonkian.

In the following instances fractures older than the eruptive rocks were observed. In the Tornado mine in the north end of the V. N. drift a fracture heavily mineralized terminates abruptly against an east-west dike, the silicification covering a slightly increased area at the point of contact. It can be observed again on the opposite side of the dike, but there is no evidence of fracture in the porphyry. In the Two Johns mine, in Squaw Creek, a fracture trending N. 68° E., which had carried ore for more than 420 feet, is interrupted by two small phonolite dikes. These dikes are about 20 feet apart, and the fractures do not pass through them but terminate abruptly against them on either side. The porphyry at the contact is slightly silicified. In the western drifts of the Two Johns mine three ore shoots terminate against a sloping wall of dark-colored rhyolite-porphyry. The fractures do not extend from the ore into the porphyry. A further indication of fractures older than eruptives is the parallel alignment of dikes and the northwest system of fractures in the Ruby Basin district, showing that the fissures through which the eruptives had gained access to the Cambrian strata were probably due to the same causes as those producing the other fissures of the same system.

From the data, then, it is to be inferred that either there are two sets of fractures, one older and one younger than the eruptive rocks, or that there have been several periods of intrusion. It has been shown that the eruptives are due to a single period of igneous activity during which many types of rock were produced, and that the transection of one rock by another may show one sequence at one point and the reverse at no great distance. It has also been shown that the intrusions followed lines of weaknesses developed by orogenic movements—the same movements that produced the fractures. It is not, therefore, necessary to assume that fractures older than eruptives at one point were formed at a period widely separated from those which show the reverse relationship at another. The fracturing, intrusion, and orogenic movement were probably coeval and occurred during one long period of mountain-making movements, so that the differences in relative age of the fractures and eruptives were due rather to irregularities in the sequence of the porphyries than to separate periods of fracturing.

ORIGIN OF THE FRACTURES.

Throughout the northern portion of the Black Hills not only does the Cambrian lie unconformably on the eroded surface of the upturned Algonkian rocks, but it rarely retains its original horizontal position. Low undulations or incipient folds of irregular form are characteristic features of the lower members of the series. When revealed by the mine workings the lower beds of quartzite are generally found to dip at a slight angle in a direction that is sometimes at right angles to the prevailing strike of the Algonkian rocks; at others without definite relations to them. Slight dips in one direction soon give place to corresponding dips in another direction, so that the whole lower surface of the Cambrian is composed of a succession of depressions and undulations with much attendant fracture and slight faulting. In explanation of this phenomenon Dr. T. A. Jaggar has suggested that during the uplift of the Black Hills orogenic movements were accompanied by a differential gliding of the Algonkian rocks upon one another along planes of schistosity. This produced an elevation at one point and a simultaneous depression at another, so that the result has been a general distortion of the horizontal layers of the Cambrian. During such differential movement the harder beds of the Algonkian have exerted a powerful upward thrust on the overlying series, the softer adjacent layers being distorted against the rocks above. Such distortions have been observed at several points. The most striking instance may be seen in the long west crosscut from the Mogul mine, which penetrates the contacts of the two series. The softer rocks of the Algonkian are here crushed against the overlying quartzite and distorted, while the more rigid members of the same series have not suffered appreciable deformation. It is not improbable that some of the breccias that occur along many of the intruded dikes are to be attributed to the same cause. Such a distortion of the Algonkian surface could not but have produced strains in the horizontal rocks above, and probably it is in large part to such strain that the fractures, with which are associated the siliceous ores, owe their origin.

RELATION OF THE FRACTURES TO THE MINERALIZATION.

The mineralization that has occurred along the fractures manifests itself in two different ways: First, it has replaced the wall rock whenever that was composed of soluble material; second, it has filled such open spaces as existed in the fractures. The distance to which replacement has extended from the fractures varies with the character of the beds through which they pass and the intensity of the mineralizing action. In comparatively impervious rocks, like shales and eruptives, replacement has extended characteristically to very slight distances, so that the result has been the production of narrow verticals. In the dolomite or ore-bearing beds proper, if slight, it has likewise produced narrow shoots or verticals; if of greater intensity, ore bodies of workable size.

In the latter case the evidence seems to point to a limited distance for mineralization arising from a single fracture. In most of the ore bodies which occur in Ruby Basin the mineralization has not extended very far. Ten feet may be considered a very fair average. Ore bodies of greater width than this are due either to the coalescence of a number of parallel shoots or to the existence of a large number of intersecting fractures. There are instances where mineralization seems to have extended to much greater distances. Thus in the vicinity of Portland extremely wide shoots were seen in which the ore extends to at least 50 feet on either side of a single fracture, and a few cases were noted where no fractures at all could be detected in the beds overlying the ore. In these cases, however, it is probable that the fractures terminated in the ore-bearing rock. Indeed, such could often be inferred from offsets in the banding of the ore, so that there seems little probability that mineralization has extended to a greater distance than 20 feet from the supplying fissure.

It will thus appear that the relation of the fractures to the separate shoots of ore depends upon the manner in which the fractures are grouped. Ore bodies occurring along single fractures are long and narrow and rarely attain a width greater than 20 feet; they are generally from 6 to 10 feet wide. Instances of this kind are the Boscobel shoot, which is 1,050 feet long with an average width of 10 feet, and the E shoot of the Tornado mine, 835 feet long by 12 feet wide. There are also many others. Where a number of fractures lie close together, so that the mineralization from one fracture has coalesced with that from the next succeeding fracture, shoots have a width determined by the number of fractures present. Of the many large shoots formed in this way two distinct types are to be found. The first includes those shoots in which the fractures are parallel, or nearly so; the second, those in which they intersect. Of the former a typical instance is the northern end of the Welcome mine, where a shoot nearly 100 feet wide is formed by a series of almost parallel or slightly diverging fissures (Pl. XIII, p. 214). Of the latter—and in general it is by far the most usual type of large ore body—there are many instances, of which perhaps the most striking is the great Tornado-Mogul shoot which is 180 feet wide at the broadest point and over 4,000 feet in length.

There are few shoots of large size—unless it be those formed along a narrow single fracture—that conform throughout to any one of these types; for in one part of a shoot one grouping of fractures will prevail, and at some distance another. In general, however, these four relations of fractures and ore are sharply defined and may be readily distinguished.

The filling of open spaces is seen in a few cases, but is then subordinate to the action of replacement. The material that fills such spaces is generally a finely divided aggregate of silica. Where the crevice is narrow the silica is without definite arrangement. With an increase in width it is noticeable that fine silica lines the walls and increasingly large individuals occur toward the center, giving to the vertical a very distinct vein-like structure. When the fractures are as much as one-eighth of an inch in width the center is often left vacant and druses of quartz crystals project inward from the walls. A specimen from the Ben Hur mine shows a fracture 3 inches in width in porphyry. Along the walls on either side is a one-half-inch lining of silica from which large crystals of quartz project inward, interlocking with those on the opposite side. These crystals are often one-half inch in diameter and 1½ inches in length. Similar verticals of varying width were observed in the Two Johns mine in Squaw Creek, in Blacktail Gulch, and at other localities. Calcite, clay, manganese, and iron oxides often fill the central cavities. In some of the fractures observed in Yellow Creek the material filling the fissure is almost, if not entirely, chalcedonic silica, and the cavities are lined with even, parallel bands of this mineral. In the Dividend mine, near Portland, and in the Donelson mine, near Yellow Creek, are fractures of considerable width containing fragments of Algonkian slates and schists, which have probably resulted from the differential movement occurring along the fissures. Filled fissures rarely possess silicified walls, for the free circulation of mineralizing waters has not usually been favorable to the action of mineralization.

Besides the primary filling of open spaces, a secondary filling is sometimes found; for when fractures have once been mineralized they have not infrequently been a second time the seat of slight movement, and a reopening of the fissure has taken place. Into the cavity thus formed fillings of calcite, manganese, and iron oxides and clay have often been introduced, so that the appearance of a banded vein is not infrequent. Such secondarily filled seams are especially abundant in oxidized localities, and often much of the filling material has found its way into cavities in the ore itself, giving rise to the erroneons belief that it is an essential ingredient of the ores.

THE ORE.

MACROSCOPIC CHARACTER.

With a few unimportant exceptions, the siliceous ores are extremely uniform in their general appearance and structure. When seen in large masses the ore is generally a more or less banded rock, exceedingly hard and brittle. The banding is due to the persistence of the stratified structure of the ore-bearing beds in the mineralized rock, the shale beds usually remaining in nearly unaltered condition, while the dolomite layers have been completely replaced. Cavities of irregular form lined with crystal druses of various minerals are invariably present and give to the ores a very cavernous appearance. These may generally be seen in bodies of mineral formed by the action of replacement.

The hardness and density of the ore are so great that it can be crushed only with great difficulty. Its hard and brittle character causes it to give a harsh, grating sound when struck by steel; so that, even when it can not be seen, a blow with a pick or other implement will often serve to distinguish it from the country rock.

The texture of the ore is dense and compact, and the color when unoxidized is generally grayish blue. At times a greenish tinge is imparted by disseminated glauconite in minute grains. Ores from Yellow Creek and the vicinity of Lead are often white, or grayish white, on account of the presence of large quantities of barite. Sulphides sometimes occur in recognizable patches in the more coarsely textured ore, but generally they are present in too fine a state of division to be visible in hand specimens.

MICROSCOPIC CHARACTER.

Under the microscope the ores are seen to consist of an aggregate of irregularly bounded individuals, chalcedonic silica and quartz, through which is disseminated pyrite (see Pl. XIV, p. 214), generally without crystalline boundaries and in a state of fine division. The proportion of the chalcedonic silica to the quartz varies, sometimes one and sometimes the other being in the preponderance; in the majority of cases, however, the quartz is present in the largest amount. The size of the pyrite masses ranges from those which are distinguishable in the hand specimen to such an extremely finely divided aggregate that the mineral is scarcely recognizable even under the microscope. It is this extremely fine pyrite that imparts to the ore its peculiar bluish tinge. Residual masses of glauconite, often of considerable size, are scattered through this with greater or less frequency.

The cavities or vugs are generally lined with druses of perfect quartz crystals. Such druses are generally free from pyrite and are probably the latest added and purest portions of the silica. They are often noticeable in the hand specimen. In some instances the center of a cavity is filled with silica resembling that of the main body of the ore. In ores from certain parts of the Tornado mine original detrital quartz grains are seen here and there through the ore, being readily distinguishable on account of their rounded character and the fractures and cracks that penetrate them. Fluorite is very frequently present; it is sometimes purple, sometimes green, and again completely colorless. It is always irregularly bounded, except when projecting into cavities, when it is found in cubes often of great beauty and perfection. Ores containing appreciable amounts of alumina frequently show light-colored masses of transparent material that polarizes as an aggregate, and this kaolin-like material is almost always present in these ores in greater or less amount, and seems to vary directly with the amount of alumina and residual impurities. In some specimens the individuals of silica are of different size, and the smaller and larger are grouped together so as to form definite bands with irregular boundaries. The finely disseminated pyrite is sometimes segregated into irregular bands and patches showing peculiar swirls and eddies, and often assuming subflorescent forms. (See Pl. XIV.) Shaly layers in the ore show the usual indeterminable aggregate of finely divided minerals. Glauconite generally favors such shaly layers and appears as green to yellowish-green masses, frequently of considerable size.

MINERALS OF THE ORES.

In the order of their relative abundance the minerals of the ores are about as follows: Quartz, calcedonic silica, pyrite, arsenopyrite, barite, fluorite, gypsum, stibnite, uranium mica (variety undetermined).

Quartz (SiO_2).—This is the most widely distributed and invariable ingredient of the ores. It occurs, as above described, as an aggregate of finely divided individuals, generally of microscopic size. Clear glassy crystals form druses lining the interior of cavities, and are often very perfectly developed. When the ores are extremely fine grained the silica sometimes shows a marked iridescence. Instances of this kind can be seen in the ore in the Ross-Hannibal mine, in Whitetail Gulch. In its origin the silica is both detrital and the product of mineralization, the latter variety generally being in far greater proportion. The detrital quartz plays but a small part in these ores, and when in large proportion materially lowers the grade of the ore. Quartz crystals of large size seldom occur, those observed in the Ben Hur mine being the single exception.

Chalcedonic silica (SiO_2+nH_2O).—Silica of this character occurs in the same general relations as the quartz, although its proportion is usually much smaller. It can not be distinguished by the eye except when it lines cavities.

Pyrite (FeS_2) Pyrite occurs in very considerable quantities in all unoxidized ores. It can often be observed in the hand specimen, but is most frequently present in an exceedingly fine state of division. In many of the ores it is so finely divided that it can not be observed without the microscope, and it then imparts a peculiar dark-blue color to the ore. The segregation of pyrite into restricted areas of the ore sometimes occurs. An important instance of this kind is reported from the Ross-Hannibal mine, in Whitetail Gulch, where a bed of pyrite is said to have underlain the ore.

Arsenopyrite ($FeAsS$).—Arsenopyrite can never be observed in the hand specimen, and often it is not present at all. In those cases where it occurs the percentage varies within wide limits, but is always less than that of the pyrite. If the rock be ground up and the sulphides isolated the white color of the arsenopyrite may often be recognized. For purposes of treatment arsenic must be determined by analysis. The analysis given on page 142 shows 4.10 per cent of this mineral.

Barite ($BaSO_4$), *heavy spar.*—Barite is in the greatest development in the

Lead and Yellow Creek areas. It occurs in flat, blade-like crystals which have sometimes a clear glassy appearance with vitreous luster or a white opaque aspect. In the ores from the Lead area it is always of the latter variety and in flat crystals which form an interlocking aggregate and frequently exhibit a rough radial arrangement. At times its relative abundance is so great that it forms more than 50 per cent of the ore, and the crystals are generally about one-sixteenth to one-eighth of an inch in thickness and one-fourth to one-half inch in width. Extremely large crystals one-half inch wide and 2 inches in length were taken from the Hidden Fortune mine near Lead. Barite sometimes occurs in massive aggregates which may be readily recognized by their great weight and the peculiar pearly appearance of their cleavage faces. Crystals from the vicinity of Yellow Creek are generally glassy and line the interiors of cavities. This mineral is rare in the Bald Mountain and Garden areas, but was found in the Boscobel shoot between Fantail and Nevada gulches. It occurs in large, flat crystals 2 inches in width and three-eighths of an inch thick. It was the earliest formed ingredient of the ore, as the rest of the rock masses closely filled the interstices between the interlocking plates. In the ore from the Penobscot mine, in the neighborhood of Garden, small quantities of this mineral were observed. Barite shows no definite relation to the occurrences of the gold, but it is one of the most widely distributed minerals in those areas that have produced the richest ores, and is an indication of very strong mineralization.

Fluorite ($CaFl_2$).—Fluorite is an invariable ingredient of the siliceous ores, although often in very small quantity. It frequently occurs in cubes lining the cavities in the ore. Ore from the Ross-Hannibal mine showed clusters of white, transparent cubes one-sixteenth of an inch in diameter. In some instances it is a brilliant-green color, but most frequently occurs in cubes of a bright purple. These are especially well developed in the Bald Mountain area. Besides the distinct crystals, fluorite is disseminated through the body of the ores in fine microscopic masses which never possess crystalline boundaries. Where the ore is in contact with other rocks, such as porphyry or shale, fluorite often extends beyond the ore and lines the cavities and crevices in the adjacent rock.

Gypsum ($CaSO_4$).—Gypsum, though not a common ingredient of the siliceous ores, occasionally occurs. Ores from the Double Standard shoot, between Fantail and Nevada gulches, showed irregular masses of gypsum, some of which are as much as an inch in diameter. F. C. Smith[a] also mentions gypsum as an ingredient of these ores.

Stibnite (Sb_2S_3).—Analyses frequently show the presence of antimony, but it is only in exceptional instances that is in sufficient quantity to be seen. Siliceous ores from Yellow Creek and closely associated with tungsten deposits show large

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[a] Trans. Am. Inst. Min. Eng., vol. 27, 1897, p. 415.

masses of this mineral composed of slender radiating needles often 2 inches in length. They are embedded in the silicified limestone and seem to be the earliest formed of the minerals present.

Uranium mica.—Large quantities of a greenish uranium mica are reported to have occurred in association with the ores of the Ross-Hannibal mine in Whitetail Gulch. Uranocircite occurs in several localities in the productive mining region, and it is possible that this occurrence is similar.

ALTERATION OF THE ORES.

The general appearance of the siliceous ores is so much changed by oxidation that the commonly accepted classification in mining circles is a division into blue or unoxidized ores and red or oxidized ores. The blue ores are those just described and grade by gradual transitions into the more oxidized varieties. All stages in the process of oxidation are well represented. The red ores are so called on account of the heavy staining with iron oxides that has resulted from the alteration of the pyrite and the infiltration of iron from other sources. They are often of an extremely ferruginous aspect, but when broken the more solid portions are found to contain but small quantities of iron oxide. Often the oxidation has begun along the line of demarcation between the dolomite and the ore, so that a very narrow line of iron-stained rock intervenes between the two. Examples of this were observed in the Ross-Hannibal mine in Whitetail Gulch. In a few cases oxidized zones were observed adjacent to crevices in bodies of blue ore. The changes which oxidation produces in the mineralogy are quite noticeable. Pyrite is the first mineral to be attacked, and rapidly passes through a series of alterations that eventually produce oxides. In most cases where the change is complete much, if not all, the sulphur has disappeared, or, if present, is changed to sulphates. In many of the ores are cavities lined with small druses of jarosite, which has formed by the oxidation of the pyrite in the presence of the potash contained in the residual shales. Calcite is an extremely common mineral in the oxidized ores, frequently occurring in such large quantities that reduced rates for their treatment can be obtained from smelting companies. It almost always fills secondary crevices or cavities which have been previously vacant, and its practical absence from the sulphide ores is strong evidence that it has been one of the minerals introduced by oxidizing waters. Black oxide of manganese mixed with limonite has frequently been similarly introduced and occurs in cavities and fissures. Its derivation, like that of the calcite, is probably due to the oxidation of the dolomite, in which the ore bodies occur. Hematite sometimes occurs in distinct scales and crystals, but is not often a noticeable mineral. Very advanced stages of decomposition produce in the ores a concentric and subconchoidal parting that causes the ore to break into kidney-shaped masses. Such structures are seen in the Big Missouri mine near Lead, the Steward mine in Nevada Gulch, and many others.

CHEMISTRY OF THE ORES.

The following table includes four analyses of refractory siliceous ore:

Analyses of refractory siliceous ores.

	I. Sulphide ore.	II. Oxidized ore.	III. Oxidized ore [a]	IV. Sulphide ore.[a]
	Per cent	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2	75.23	65.142	84.45	68.748
TiO_2	.13			
Al_2O_3	3.61	3.924	4.07	3.072
Fe_2O_3	.13	20.364	7.28	
FeO		.065		
Fe	5.83			13.289
MnO		Trace.		
MgO	Trace.	.779	.25	
CaO	1.75	5.711	.85	
SrO	Trace.			
BaO	.05			
Na_2O	.05	Trace.		
K_2O	2.38	Trace.		
Li_2O	Trace.			
$H_2O-105°$	.47	.476		
$H_2O+105°$	.87	1.839		
P_2O_5	.21	.832		.842
SO_3	.61	.073	3.71	
$CaSO_4$				.833
S	5.85	.279		11.728
Fl	.62			
$CaFl_2$				.784
Cl	Trace.			
As	1.89	.010		
Sb	[b] .02	Trace.		
Cu	[b] .02	Trace.		
	99.72			
Less O for Fl	.29			
Total	99.43	99.957	100.61	99.296
	Oz. per ton.	*Oz. per ton.*	*Oz. per ton.*	*Oz. per ton.*
Gold	2.95	0.42	0.574	0.325
Silver	4.75	.62	2.875	10.55
Tellurium	(c)		8.426	4.03

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[a] Taken from paper "Potsdam gold ores of the Black Hills of South Dakota," by F. C. Smith: Trans Am. Inst. Min. Eng., vol. 27, p. 415.

[b] Approximate.

[c] Enough present to form telluride with the gold if not with the silver.

Analysis I is of sulphide ore from the No. 4 shoot, Double Standard mine. This specimen was completely unoxidized, showed considerable pyrite, visible in the hand specimen, some arsenopyrite, kaolin, and other residual shaly material of indeterminable character. Analysis was made by W. F. Hillebrand. It was not possible to calculate the percentage of all the minerals present on account of the uncertain composition of the shaly material, but the following minerals could be easily estimated:

Mineral composition of sulphide ore from No. 4 shoot, Double Standard mine.

Pyrite	9.47
Arsenopyrite	4.10
Stibnite	.03
Fluorite	1.36
Gypsum	1.31
Barite?	.08
Apatite?	.49
Rutile?	.13
Silica, together with detrital clay, etc.	82.46
Total	99.43

The potash, alumina, and traces of lithia, magnesia, and strontia are probably contained in the shale. Phosphorus has been estimated as apatite, on account of a slight excess of lime over that necessary to combine with the residue of SO_3. Apatite could not be distinguished as such, but as phosphorus is present in the unmineralized country rock and ore in approximately equal amount,[a] and so often occurs in shales, its presence may be justly assumed. The titanium may likewise be present in the shaly material, possibly as rutile. The percentage of potash in this analysis is rather unusually high, and, taken in connection with the aluminum, might be regarded as indicative of orthoclase. Assuming the presence of orthoclase and about 2½ per cent of kaolinite, there would be about 60 per cent of free silica.

Copper never occurs in any considerable quantities and in much of the ore can not be detected at all. Arsenic is present as arsenopyrite and antimony as stibnite. Gold and silver can not be identified by the microscope, but tellurium is present in sufficient quantity to combine with them to form tellurides. This is also shown by Professor Smith, who has calculated the percentage of tellurium, gold, and silver and shown them to be present in the proportions requisite for the composition of sylvanite. There seems to be little reason to doubt that gold and silver are present in this combination. One of the most important features of this analysis is the complete absence of carbon dioxide and the correspondingly

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[a] Compare analysis of dolomite on p. 121.

low percentage of lime, manganese, and ferrous iron, showing that the soluble constituents or carbonates have been almost, if not completely, removed during the process of silicification.

Analysis II, of oxidized ore from Blacktail Gulch, was furnished by the courtesy of Mr. Dorr, of the Golden Gate Mining Company, and is published by permission of the company. This analysis is chiefly interesting as illustrating the chemical changes brought about by alteration. The great increase in iron oxide, lime, and magnesia, with the corresponding fall in silica and sulphur, are the most conspicuous features. The increase in iron oxide, lime, and magnesia are probably due in large part to the infiltration of these ingredients from without by the action of surface waters, the iron in the form of oxides and the lime and magnesia in the form of carbonates. The moisture is also much higher. The other ingredients have probably not suffered appreciable change.

Analyses III and IV are of oxidized and unoxidized ores, respectively, and show in general the same series of changes, but in this case the blue ore, IV, is much more basic ore than III, so that the increase in iron would at first seem to be reversed. In general an examination of about 35 analyses furnished by the Deadwood and Delaware Smelting Company showed a range in silica from 60 to 86 per cent and of iron from 5 to 17 per cent, or an average of 73.36 per cent silica and 12.17 per cent iron.

It is difficult to offer any satisfactory explanation of the failure of the gold in these ores to yield to ordinary methods of extraction. In the case of the blue or unoxidized ores its probable combination with tellurium may be considered a sufficient reason, but for the red or oxidized variety, or the blue when subjected to a thorough roasting, by which it is to be supposed that the gold is either wholly or at least in part released from combination, this will not answer. That the gold is, as originally supposed by Devereux, in an extremely fine state of division and is uniformly distributed through a rock not readily permeable by solutions and yielding with difficulty to crushing may be offered as a partial explanation of the refractory nature of the ore. It must, however, be admitted that with all of the endeavors to solve this problem the exact condition in which the gold exists in these ores is not well understood.

VARIATIONS FROM THE USUAL TYPE OF ORES

Four varieties of ore are found intimately associated with these siliceous ores, but can not be considered characteristic.

Auriferous clay.—In the Mogul and Tornado mines there occur, interbedded with the hard siliceous ore, bands of a soft white clay which frequently carry higher values in gold than the main body of ore. Seams of this kind are reported to have contained at times from $40 to $60 per ton in gold and to have yielded free gold on panning.

It is not possible from an examination of the material to form any very definite idea of its origin, but the clayey matter is probably the result of the decomposition of intercalated shale or of small included layers of porphyry. For the introduction of the gold the writer can suggest no satisfactory explanation unless it be the result of the secondary action of surface waters on the ore material above.

Auriferous sand.—Below the ore and lying in the quartzite in the Wasp No. 2 mine in Yellow Creek, or directly upon the Algonkian in the Dividend mine near Portland, was found much loose incoherent sand containing considerable values in gold. In both cases it was partially cemented by limonite or carbonates and often yielded very high values. When washed and examined under the microscope the grains of sand from Yellow Creek were found to be loose and often perfect crystals of quartz and only held together by the cementing material.

Auriferous gouge.—In the Dividend mine, near Portland, much of the decomposed dolomite is heavily charged with oxides of iron, together with some sandy fluorite and manganese. It carries workable quantities of gold. The values are, however, always lower than those of the silicified rock occurring in their immediate vicinity. It is not improbable that this gouge material is the result of both primary and secondary mineralization. The presence of fluorite, which is a mineral that often extends beyond the limits of silicification into crevices in the adjoining rocks, suggests that the values were partially introduced into the dolomite at the time of first mineralization; the presence of manganese, that a secondary concentration of such values by surface waters has taken place.

Quartzite ore.—The quartzite that underlies much of the siliceous ore of the lower ore-bearing beds contains a high percentage of carbonates, and it is not infrequently mineralized so as to form pay ore. It is never as high in grade as the ore that lies above it, because there is more insoluble material in the original rock than in the purer dolomite beds above.

AREAL DISTRIBUTION OF THE REFRACTORY SILICEOUS ORES.

The productive areas of refractory siliceous ores are five in number (see Pl. V), and have been severally designated the Bald Mountain area, Lead area, Yellow Creek area, Garden area, and Squaw Creek area. The last-named area was at the time of examination little more than a prospect, but has since become an important producer.

BALD MOUNTAIN AREA.

This is by far the largest and most important area, and has justly been considered the type district for this class of ores. Its name has been derived from Bald Mountain, which lies at the center of the northern edge of the area.

As will be seen from Pl. V, it is a northwest-southeast striking belt of about 1 mile in width and 4½ miles in length. As it corresponds closely to the inner rim of exposed Cambrian strata, it lies between the contact of that rim with the underlying Algonkian on the northeast and the nearly parallel line of contact of the Cambrian with the overlying Ordovician on the southwest. Across this belt the Cambrian beds have a general downward inclination from northeast to southwest. They have been eroded from the higher portions of the Algonkian area to the northeast (with the exception of a few isolated outliers), and pass on the south beneath the heavy, overlying rocks of the Ordovician and Carboniferous formations.

This belt of Cambrian rocks extends on to the southeast beyond the present limits of the productive area, but is cut off from the Yellow Creek area by the deep gorge which the waters of Whitewood Creek have cut far down into the Algonkian. Toward the northwest the Ordovician and Carboniferous approach much nearer to the edge of the Algonkian area and the rim of the Cambrian turns toward the north. In its northern end, in the vicinity of Crown Hill and Portland, the Cambrian is exposed in nearly its full thickness, so that as yet it is only the upper ore-bearing beds that have been thoroughly developed. As will appear from Pl. IX, great numbers of intrusive sills, dikes, and irregular bodies of igneous rock are interbedded with the Cambrian rocks of this belt.

The topography of this area is very rough and irregular, the steepness and irregularity of the gorges having been much accentuated by the presence of eruptive bodies, which have offered great resistance to erosion, while the softer inclosing Cambrian rocks have been more readily removed.

From a northwest-southeast line through Terry Peak the drainage is to the southwest into Spearfish Creek, to the northeast into Whitewood Creek and to the northwest into Squaw Creek.

The headwaters of the southwest drainage appear just at the edge of the area, and have cut down through the Carboniferous rocks into the Cambrian, leaving heavy cappings of the former on the divides between the streams. The northeastward drainage comprises a series of gulches which empty into Whitewood Creek. These streams head up into the Cambrian belt and cut down into the underlying Algonkian, so that the lower ore-bearing beds, which are about 10 to 25 feet above the Algonkian, outcrop in a very sinuous line, and allow long, narrow embayments of Algonkian schists to extend far up into the mining district. The southeastern portion of the district has been more deeply dissected, so that the ore-bearing beds have here been rendered easy of access on the divides between these gulches, especially on Nevada, Stewart, and Whitetail creeks. In the northeastern portion, erosion has not progressed so far, and the lower ore-bearing beds are still in large part deeply buried, the so-called upper contact having been most extensively developed.

With relation to the ore bodies, therefore, the area may be divided into two portions—the Ruby Basin district and the Portland district. In the first-named, or southeastern district, the mines are largely upon the lower ore-bearing beds; in the second, or northwestern, largely upon the upper. The mines of the Ruby Basin district are operated mainly by one company—the Golden Reward. Two mines belong to the Portland Company, namely, the Big Bonanza and Buxton, while a few small mines are operated by individual owners. These relations may be clearly made out from Pl. IX.

RUBY BASIN DISTRICT.

In the Ruby Basin district there are a large number of long channel-like ore bodies or shoots resting on or near the basal Cambrian quartzite and trending as a whole in a roughly north-south direction. These ore bodies fall into two distinct groups, within which ore shoots are situated relatively close to one another. These are the Buxton-Union group and the Alpha-Plutus-Mogul group.

Buxton-Union group.—This is the more easterly of the two, and comprises 15 mines. Naming them from the east to the west, beginning on the north, these are: The Buxton, Retriever, Steward, Tony and Maggie, Golden Reward, Big Bonanza, Little Bonanza, Gladstone, South Golden Reward, Fanny, Isadorah, Sundance, Billy, Ruby Bell, Lucille, Union, and Ross-Hannibal (or Mikado). (See map, Pl. IX.) The ore shoots operated in these mines number 39 in all, of which 21 are large and extensive and the remaining 18 comparatively insignificant. The general trend of these shoots is about north-northwest, with a few large intersecting shoots trending N. 25° E., or nearly so.

The ore-bearing beds upon which the mines of this group are situated are not continuous in a north-south direction, but are cut through by Fantail and Stewart gulches, so that the ends of the ore bodies outcrop on either side of the divide separating these streams, rendering them easily accessible. The ore-bearing beds, however, are at a much lower elevation at the southern end of the group, so that the shoots in the Union mine have been worked by means of a shaft.

At the southern end of the group a large sill of phonolite has been intruded in the Cambrian, and extends westward as far as the Fanny mine. It may be seen making abrupt cliffs in Stewart and Whitetail creeks. South of Whitetail Gulch this sill has cut the ore-bearing beds into two portions, so that the shoots of the Union mine lie below and that of the Ross-Hannibal above, the phonolite forming in the one case the roof and in the other the floor of the ore. The workings of the Isadorah and South Golden Reward are also above the phonolite, but they rest upon the quartzite so that (as may be seen in the Billy tunnel) it is evident that the phonolite has cut downward toward the west and included all of the ore-bearing beds above itself. This sill is extremely irregular, and presumably terminates at the northern end of the South Golden Reward, where it extends upward in a dike-like mass separating the ore bodies of the north and south end of the Golden Reward. It extends northwest, however, beneath the southern end of the Big Bonanza, and sends out a dike toward the north which separates the Big and Little Bonanza mines, the former being about 50 feet above the latter. The ore bodies of the North Golden Reward and Tony and Maggie outcrop in the south side of Fantail Gulch, and are on the lower Cambrian quartzite, which is separated from the Algonkian by a heavy sill of eruptive rock. The Big Bonanza is at about the same elevation, and is separated by the same sill from the Algonkian. Owing to the abrupt termination of the thick phonolite sill previously mentioned, the ore body of the Fanny mine is much lower in elevation than that of the mines directly east, and it is at about the same elevation as the shoots of the Alpha-Plutus-Mogul group to the west. The shoots of the Little Bonanza outcrop just west of the Big Bonanza, and are much complicated by irregular porphyry bodies. As their relations are more fully discussed on page 187, they will not be further mentioned at this point.

Alpha-Plutus-Mogul group.—This group is separated from the more easterly, or Buxton-Union group, by a wedge-shaped area of comparatively barren country situated with its broader end toward the south, so that the two groups approach each other on the north, but diverge in a southerly direction. This group comprises 14 mines. From east to west beginning at the north, they are as follows: Clinton, Alpha-Plutus, Smily and Lundt, Bottleson, Tornado, Little Tornado, Double Standard, Boscobel, Daisy, Harmony, Hardscrabble, Welcome, Upper Welcome, and Great Mogul. There are 71 shoots in all, of which about 25 are of large size, the remainder being small, though yielding collectively a large amount of ore. One, the Tornado-Mogul shoot, is larger than any yet discovered. With two exceptions all of the ore bodies of this group lie in the lower ore-bearing beds close to the Algonkian, or not more than 30 feet above it. Two small ore bodies, the Daisy and Upper Welcome, the first situated on the divide between Fantail and Stewart gulches, and the second on the north side of Nevada Gulch, are on an upper contact, which probably corresponds to that of the upper ore bodies of the Portland district.

As will be seen from Pl. IX (p. 214), the shoots of this group trend northwest-southeast and are comparatively close to one another, relatively few of them being disconnected. The group is broken into two portions by a heavy fault by which the ore-bearing beds on the west side are elevated about 300 feet and offset against the higher measures of the Cambrian. On the lower, or east side, of the fault the same beds are offset against the Algonkian. This fault appears as a single and clearly cut displacement in the west workings of the Troy shaft where it has been well exposed in the several crosscuts that connect the Horseshoe shaft with the stopes of the Great Mogul. From this point it passes northeast, but becomes in part divided into many small step faults between the workings of the Hardscrabble and Tornado mines; thence it runs north across Nevada Gulch separating the workings of the Alpha-Plutus from the small tunnels of the Smily and Lundt mine. This fault is not clearly defined on the surface, because there are so many complicating masses of intruded rock that distort and confuse the relations of the strata. It appears, however, in Nevada Gulch at the point where the Fremont, Elkhorn, and Missouri Valley Railroad makes a horseshoe bend, the Algonkian extending far up the gulch but coming against the upper Cambrian at this point. Just south of Nevada Gulch this fault is immediately on the west side of a large dike of eruptive rock, but diverges from it in a southerly direction so that in the Troy workings the two are separated by an intervening area of about 800 feet. That this fault diverges thus from the porphyry suggests that it is widely separated in age from the intrusion, a fact that is well borne out by other evidence. A second fault also appears just west of the Mogul shoot, at the extreme south end of the group, and on the west side of the large porphry dike that extends north as far as Nevada Gulch, forming the western boundary of the great Tornado-Mogul shoot. The downthrow of this fault is to the west, the reverse of that just described. It lowers the ore-bearing beds fully 100 feet at the extreme south end, but gradually dies out northward until, at a point about the center of Fantail Gulch, it has completely disappeared. A third fault occurs at the north end of the group about 300 feet east of the 300-foot fault and with the central point of its course just below the bed of Nevada Gulch, the downthrow being about 72 feet on the east. It has a general north and south direction, but curves to the west as it is followed south, cutting the Tornado shoot into two portions and uniting with the 300-foot fault. Upon the fault block thus formed are the north end of the Tornado, otherwise known as the St. Louis shoot, and the most westerly ore bodies of the Alpha-Plutus. As may be seen by consulting Pl. IX, only three of the shoots of the part of this group below the 300-foot fault show in outcrop, the gulches not having been cut deep enough to dissect the ore-bearing beds. Of these three the Clinton outcrops in Nevada Gulch, but as it is about midway between this group and that first described it can not be rightly said to belong to either of the two. The other two, the St. Louis and Upper Alpha-

Plutus, are on the small elevated fault block and outcrop in Nevada Gulch. The remainder are all deeply buried and have, therefore, been worked by means of shafts. The relations of these faults to one another may be understood by consulting Pls. XIX and XX (p. 214).

West of the 300-foot fault the ore shoots outcrop all along the south side of Nevada Gulch. Two mines, the Little Tornado and Harmony, outcrop also, one on either side of Fantail Gulch. To the southwest, however, the ore-bearing beds are not exposed and mining is carried on by means of shafts.

PORTLAND DISTRICT.

With one exception—the Dividend mine—the ore shoots of the Portland district are on the so-called "upper contact." They are separated from the lower ore-bearing beds by a vertical interval of 527 feet, and are about 15 to 25 feet below the *Scolithus* or "worm-eaten" quartzite. They comprise a series of shoots all closely grouped together and striking with almost no exceptions about east-northeast, thus showing a marked difference in trend to those of the Ruby Basin district. The following mines have been operated: Dividend, Decorah, Trojan, Empire State, Folger, Perseverance, Alameda, Leopard and Jessie Lee, Mark Twain, Burlington and Golden Sands, Clinton, Portland, and Gunnison. There are about 46 productive shoots in this group, but they are so often connected with one another that it is difficult to say where one ends and the other begins. The ore-bearing beds dip slightly to the southwest, so that they outcrop around Green Mountain and westward just above the two railroad lines at the head of Squaw Creek, and also at the head of Nevada Gulch. To the southwest they are more deeply buried. These shoots are as a rule rather broad and flat as compared with those of the Ruby Basin district. Little or no faulting occurs, so that the geological relations of the group may be readily appreciated from Pl. IX (p. 214). The lower ore-bearing beds outcrop 527 feet below, at the base of Green Mountain, around the head of Deadwood Gulch. The workings of the Dividend mine are situated here, but have not yet been extended sufficiently far to the southwest to fully explore this contact directly below the upper workings, and it is therefore not possible to say whether the presence of these ore bodies on the upper beds may be considered as evidence that a correspondingly productive group of ore bodies will be found below. The ore from this group is in much thinner shoots than that occurring in the Ruby Basin district, and the ores, taken as a whole, yield rather lower values than the general run of lower contact ores. This difference in value is especially noticeable when the comparison is made between them and the ores from the Dividend, which belongs to the same group. Ores from this mine yield between one-third and twice as high values as those from the upper group.

Heavy sills of eruptive rock lie at varying distances below the beds upon which the mines of this group are operated, and the summits of Green Mountain and the hills to the south are capped by a mass of the same character. Dikes are noticeably absent from the workings, only one having been encountered. In the workings of the Dividend, however, the dikes are extremely abundant, a fact which shows that there is a strong tendency for intrusives to assume horizontal positions as they ascend to higher horizons in the Cambrian. As compared with the Ruby Basin district the absence of dikes in this area is significant, as it shows that the occurrence of these ores is in no way dependent on their presence.

ISOLATED MINES.

Besides these large groups of ore bodies there are several isolated mines that may properly be classed as in the Bald Mountain area. Two of these are in Nevada Gulch, about midway between the Ruby Basin and Portland districts. These are the Baltimore and Ben Hur. The former has a series of small shoots lying on the lower contact, which is at this point some distance vertically below the bed of Nevada Gulch. The workings are largely to the south of the gulch. The Ben Hur is some distance farther down the gulch, just at the head of the Algonkian exposure (see Pl. IX, p. 214). A small north-south fault has lowered the strata on the west so that the single shoot of this mine is worked by means of a tunnel through the schist.

The area between the Alpha-Plutus-Mogul group and the Portland group is about 3,000 feet in width and has been quite extensively prospected, notably by the Snowstorm mine, but as no other than these two ore bodies have been found it seems not improbable that it may constitute a comparatively barren area like that between the Buxton-Union and Alpha-Plutus-Mogul groups.

Another isolated mine is the Two Johns, operated on the lower ore-bearing beds which outcrop on the west side of upper Squaw Creek. The shoots trend east-northeast, but are all comparatively small. A little ore has also been found in the South Dakota mine in Annie Creek and at other points along the course of Squaw Creek, notably in the Labrador mine, but this western portion of the Bald Mountain area has not yet been thoroughly prospected, though it may in future become productive territory.

GARDEN AREA.

The mines of the Garden area are situated in Blacktail and Sheeptail gulches, and at the head of a small tributary of False Bottom Creek about two-thirds of a mile east of south from Garden. To the southwest lies the Algonkian nucleus of the northern portion of the hills. To the north the country is covered by a heavy cap of rhyolite which obscures the relations of the Cambrian strata. Still farther north the Cambrian passes beneath the overlying formations. The strata dip quite sharply to the northeast and are covered by the rhyolite cap before mentioned. The relations of the strata are much confused by irregular intrusives and by a series of small north-south faults which elevate the ore-bearing beds on the west side. The following mines have been operated in this area: Penobscot, Golden Gate, Wells Fargo, Kicking Horse, Keystone, American Express, Chicken Lode, and another mine of considerable size whose name is not known.

The trend of the shoots is about east-northeast by east or nearly east-west, although there is considerable divergence from this direction. The shoots are somewhat narrower than those of the Bald Mountain area, but generally of considerable length. The grade of the ore is comparatively low on account of the prevalence of shale bands in the ore, but some high values have been reported. Dikes are seldom if ever encountered in the workings. The exposed area of Cambrian upon which these mines are situated is very limited, and it is not known how far the ore-bearing beds extend beneath the rhyolite cap to the northeast.

LEAD AREA.

In the vicinity of Lead there still remain uneroded on the crests of the Algonkian ridges a few small isolated outliers of Cambrian strata. A heavy sill of fine-grained rhyolite caps the Cambrian, leaving a varying thickness of shales, dolomite, and conglomerate between it and the Algonkian, but as we approach the Homestake zone, first this rock and then the basal conglomerate thins out so that the ore-bearing beds lap over first upon the conglomerate and finally directly upon the schists. The ore bodies are exposed at the surface upon the westernmost edge of this area, but lie beneath the shales in an easterly direction. Much of the ore from this district contains great quantities of barite and is uniformly rich in gold. From the Hidden Fortune mine was taken ore which, in addition to its refractory content, yielded immense quantities of finely divided and crystalline native gold. From the thin parting of ore-bearing beds above the De Smet cut, and below the rhyolite cap, great masses of very rich siliceous ore were mined, while to the west of the Homestake open cut the Big Missouri mine has yielded great quantities of ore of the same character. In those mines where the conditions permit of their determination the fractures with which the ores are associated conform in strike to the lamination of the underlying Algonkian schists.

YELLOW CREEK AREA.

This area is situated a little more than 2 miles slightly east of south from the city of Lead.

The ores are found in a thin capping of Cambrian strata on the divide between Whitewood Creek on the west and Yellow Creek on the east. Above the Cambrian rocks is an extensive sill of fine-grained rhyolite which attains a thickness of 350 feet as it is followed in a southerly direction. A small detached area of this eruptive rock remains uneroded to the north and there forms a small elevated knoll. Between this knoll and the larger southern mass of porphyry the Cambrian measures lie uncovered, and within this area—generally not more than 30 feet below the surface—have been found small but rich bodies of refractory siliceous ore. Farther to the north on the extreme end of the divide is a large mass of phonolitic rock intruded irregularly into the rocks of the Algonkian. On the northeast side of Yellow Creek small areas of Cambrian still remain upon the crest of the divide between that creek and the west branch of West Strawberry Creek. Siliceous ores have recently been found on this divide, but have not yet been much developed. The ores of the Yellow Creek area lie directly upon the basal quartzite of the Cambrian and about 15 to 25 feet above the Algonkian. They follow fractures varying somewhat in their direction, but the more extensive shoots generally trend northwest and southeast, following the strike of the Algonkian rocks. In the greater number of the mines the loose incoherent character of the roof has completely obscured the supplying fractures. The average value of the ores is about $40 to $50 per ton. In the Minnie mine the grade was much lower and in other mines much higher. Fluorite is generally not a prominent constituent, but barite occurs with great frequency. The mines which have so far been operated here are the Donelson fraction, Wasp No. 1, Little Pittsburgh, Two Strike, Minnie, Little Blue, Little Blue fraction, Wasp No. 2, and Wasp No. 4.

The Yellow Creek district, though a very restricted one, has been extremely productive on account of the high average yield of the ore. The district is closely related to that near Lead. The grade of the ores in both cases is high; the occurrence of barite and tungsten minerals is similar, and the two areas bear the same general relation to the strike of the Homestake ore body. To a less extent it is similarly related to Garden area.

SQUAW CREEK AREA.[a]

This area is situated in Squaw Creek, a short distant east of its junction with Spearfish Creek. It is one of the few where mining has been begun in the bed of a deep gorge, with a very narrow outcrop of Cambrian capped by heavy Carboniferous cliffs, so that mining will soon carry the workings beneath great thicknesses of overlying rocks. A few verticals may here be seen and some small bodies of ore have been encountered in the Cleopatra mine, although at a considerable distance above the base of the series. In view of the heavy mineralization of the overlying Carboniferous it is not improbable that ore bodies of workable size may be found here. At present it is little more than a prospect.

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[a] After this paper had gone to press C. C. O'Harra's paper "The mineral wealth of the Black Hills," was received, showing that this Squaw Creek area had become an important producer since the writer visited the region.

SUMMARY.

The refractory siliceous ores are restricted to certain soluble strata of the Cambrian series. Such development as has taken place has naturally been directed to those areas of Cambrian strata where erosive agencies have rendered the ore-bearing beds most readily accessible.

The Cambrian rocks are not widely exposed, as they yield readily to erosive agencies when unprotected by a capping of massive limestone. They therefore remain only as a rim around the inner edge of the Carboniferous (see Pls. V and IX), and rapidly thin inward until only isolated outliers remain upon the Algonkian highlands, or they pass outward beneath the heavy massive rocks of the Carboniferous. In the former case ore-bearing areas are isolated on account of the removal of the Cambrian strata from the intervening country. In the latter case the ore-bearing beds lie so deeply buried that it is difficult to say how far in these directions the mineralized area may extend, and exploration involves a greater expense than the uncertain conditions would seem to justify.

VALUE OF THE ORES.

The gold contents of the ores in the Bald Mountain area run from $3 or $4 per ton to, in rare instances, $100. The general average for the ores in this district is about $17, and those containing from $10 to $20 are of the most common occurrence. Ore carrying $35 per ton is considered high grade. Some of the ore from the Ben Hur mine yielded upward of $60 per ton in gold. As compared with the ores of the lower beds those from the upper contact are slightly lower in grade, so that much of the ore is often left in the mines. The ores from the upper contact have also been reported to carry a higher relative proportion of silver, but although this is true in individual instances, in general, silver ores are as frequent in the lower as in the upper beds. The distribution of the values in the ore is far from uniform. Ore which carries $25 at one point will fall, within 10 feet, to rock yielding only $10. This is especially true of the upper contact. In general, the larger ore bodies are of lower but more uniform grade. No general rule as to the distribution of values in a single shoot can be laid down, for the portion near the supplying fracture is sometimes higher and sometimes lower than that farther removed therefrom. The extreme "rims" of the ore are generally lower than the main ore mass. In the Tornado mine the ore in the vicinity of the complex of dikes and faults north of the shaft carried higher values than that in the less disturbed beds to the south. In the Ross-Hannibal mine, on the contrary, the ore carried very high values and the shoot was remarkably uniform and undisturbed. The larger ore bodies often yield increased values where they are joined by smaller shoots entering them at an angle. Instances of this are to be seen in the Tornado mine.

The three smaller areas of siliceous ore, Yellow Creek, Lead, and Garden, to the west of the Homestake ore body, or its continuation, produce ores of uniformly higher grade than those from the Bald Mountain country. Those of the Lead area, such as the Big Missouri, Durango, and Harrison, yielded ores carrying between $25 and $500 per ton; much ore was shipped that carried an average of $50 per ton. The unusual instances are the Hidden Treasure, Golden Crown, and Iowa mines; portions of the Durango and Harrison also produced ore containing large quantities of free gold besides that in the refractory condition. The grade here ran up into the thousands, so that one car of 10 tons is reported to have yielded $65,000. High-grade ores are also found in Yellow Creek where a conservative average for ores heretofore mined is $40 to $50 per ton.

The Garden area, which bears the same general relation to the continuation of the Homestake as do the Yellow Creek and Lead districts, also carried some ores with remarkably high values, but the general average in this district is not high on account of the large amount of waste in the ore due to the greater proportion of shale bands in the ore-bearing beds.

AGE OF THE MINERALIZATION.

The fractures have been shown to be older than some of the eruptive bodies and younger than others. Where fractures cut eruptives fillings of ore extend uninterruptedly from the main ore body into and through the porphyries. Mineralization along fractures that are cut by eruptives has always exercised an influence on the porphyry, either by producing a slight silicification at the point of contact or by the extension of the more powerful of the mineralizers, like fluorite, beyond the ore into the minute crevices of the eruptive rock. Eruptives have never been observed to contain angular fragments of ore, which would probably have been the case had magmas broken through such an extremely brittle material. These conditions have been observed to hold good for all of the varieties of eruptive rock. The mineralization is, therefore, later than the igneous activity.

As igneous rocks cut strata of the Benton Cretaceous and pebbles of the same rock have been found in the basal conglomerates of the Neocene it would seem that the mineralization occurred somewhere between the Benton and the Neocene and it probably represents the final phase of vulcanism that was concomitant with the elevation of the Black Hills. This occurred while the Cambrian was still deeply buried beneath its covering of later formations.

ORIGIN OF THE ORES.

The evidence that is furnished by the facts cited in the foregoing pages as to the origin of these ores falls into two classes, that which relates to the manner in which the ores have been formed, and that which relates to the source from which the ore minerals have been derived. The first has to do with the changes that have taken place in the country rock through the agency of mineralizing action, and with the chemical and physical nature of the process by which these changes have been wrought. The second treats of the channels through which the mineralizers have gained access to the beds which they have altered, the direction of flow of mineralizing waters through these channels; and, finally, the immediate source from which these waters have derived their mineral contents.

THE MINERALIZING PROCESS.

The ore did not in any sense fill preexisting cavities, for there is no evidence to show that such have existed in the ore-bearing rock at any time; the only cavities present being the minute crevices or fissures which have been termed "verticals." The ore has been formed by a process which involved the gradual removal of the original rock substance and the simultaneous substitution of the ore minerals. This has often proceeded with so little disturbance of the original material that the stratification of the country rock is continuous with the banding of the ore, and at times so perfect is the preservation of this structure that it is difficult to determine, without a detailed examination of the substance of the rock, at what point the ore terminates and the unmineralized rock begins. A very good idea of this banded structure can be obtained from Pl. XVI (p. 214). In other words, a complete alteration of the mineral substance of the rock has taken place without any change in its external form; still further, when viewed under the microscope, the ore shows an even more faithful reproduction of the original microscopic structure. One type of ore-bearing rock (described on page 120) consists of an aggregate of minute but complete crystals of dolomite. This rock is shown in Pl. X, *B* (p. 214). When a transformation of this material into ore has taken place the process has been carried on with such nicety that these little rhombs appear as distinct in the ore as in the unaltered rock (Pl. XV, *A*). When, however, the polarizer is applied to the microscope it is at once seen that the ore is composed entirely of silica and pyrite and that no trace of the original material is left, although its form is as perfect as before alteration (Pl. XV, *B*, p. 214).

During this mineralization a marked decrease in volume has occurred. This is shown by the great number of cavities or vugs that occur in the ore, and the resulting contrast with the dense texture of the original rock. The intensity of the ore deposition seems to have been directly proportional to the confinement of mineralizing waters; the more open the fracture the smaller is the ore shoot, and the more even and uninterrupted the shale or porphyry above, the greater is the lateral extent of the ore. Again, where ore shoots, like the great Tornado-Mogul, lie in contact with large igneous bodies, there seems to have been an additional confinement of waters which may have had some connection with the great size of the ore body.

DIRECTION OF FLOW OF MINERAL WATERS.

These ore minerals have been transported by circulating waters to the dolomite, whether it was present as comparatively pure beds or as cementing material of sandy and shaly rocks. Such waters have found in the fractures, or "verticals," trunk channels by means of which they have been enabled to penetrate the encompassing and comparatively insoluble rocks and reach the more readily replaced material. Whether the direction of flow in these fractures has been upward or downward is extremely difficult to determine, for there are certain facts that are not to be readily explained on either assumption. In the opinion of the writer, however, the mass of evidence seems to favor a mineralization by ascending waters.

In the first place, the ore generally lies immediately below a comparatively impervious rock (see Pls. XI, XIX, XX, p. 214); this may be a bed of extremely argillaceous shale, sometimes quite thin and again of considerable thickness, or a sheet of porphyry, but in all cases a rock competent to act as a barrier to the further passage of uprising waters. On the other hand, such a close contact with the quartzite or other impervious rock below rarely occurs, for there often intervenes between the next lower impervious bed and the under boundary of the ore an unmineralized area of dolomite of the same soluble character as that which has been replaced. Excellent instances of this may be seen in the Union mine, the E shoot of the Tornado mine, in the Mogul mine, the Welcome mine, the American Express mine, the Two Johns mine, and in innumerable other cases. If the mineralizing waters had come from above it is reasonable to suppose that such a stoppage of circulation would have taken place just above, not beneath, an impervious bed, and that the unmineralized portion of dolomite would have been above and not below the ore. It is, of course, to be observed that there are many cases where this unmineralized area is not present, for the ore often completely fills the space between the roof and underlying impervious bed. This is especially true where ore bodies are very extensive, for the aggregate amount of material introduced has been sufficient to completely replace all of the soluble rock which intervenes.

In the second place, directly beneath this impervious roof the lateral extent of the ore—the horizontal distance to which ore solutions have spread from the supplying fissure—is generally greatest, diminishing with increasing downward distance until it pinches to a mere vertical. It is clear that the interposition of an impervious layer across a channel of circulation will produce just such a lateral spreading, and that where circulation has been upward, it will take place on the under surface of the layer; where downward, on the upper. The two diagrams below (fig. 15) bring out these relations.

In the third place, there seems in general to be a connection between the lateral expansion of mineralizing waters and the amount of open space available for their circulation. Thus, where fractures are large and open and pass uninterruptedly upward through the capping shale or porphyry the soluble rocks are comparatively little altered and ore shoots are narrow and confined chiefly to the immediate vicinity of the fracture.[a] In other words, the mineralization of lower beds has not been great where large and open verticals have permitted the free passage of waters to higher levels. Such a stoppage of flow in mineral-bearing waters would also tend to increase the extent of rock mineralized along the barrier, owing to the increased chemical activity of the waters due to the absence of rapid motion; for it has been frequently remarked by writers on ore deposition that the quiescence of mineralizing waters is essential to an active deposition of mineral.[b]

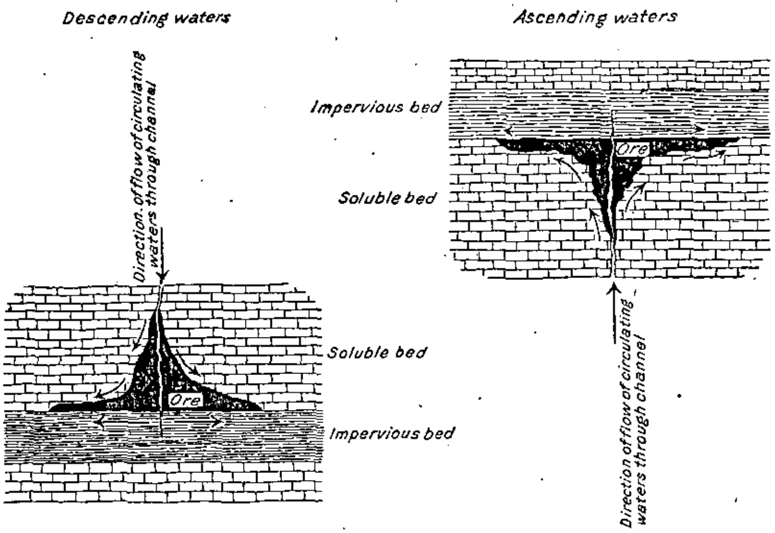
Descending waters
Direction of flow of circulating waters through channel
Soluble bed
Ore
Impervious bed
Ascending waters
Impervious bed
Ore
Soluble bed
Direction of flow of circulating waters through channel

FIG. 15.—Ideal section to show relations of greatest lateral extent of ore to direction of flow of mineralizing waters.

While these three groups of facts are not sufficient to prove that these ores were deposited by ascending waters, they must at least be explained before a deposition by descending mineralizers can be advocated.

DERIVATION OF ORE MINERALS.

There are no facts which serve to indicate with certainty the source from which the circulating waters derived their mineral contents. However, from a

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[a] Large ore shoots occur along open fractures, but only where they are present in large numbers and are closely spaced, so that small amounts of mineralization along fractures have coalesced, forming a large body limited by the number of fractures.

[b] Emmons, S. F., Geology and mining industry of Leadville, Colo.: Mon. U. S. Geol. Survey, vol. 12, 1886, p. 570. "It will be readily apparent * * * that such precipitation will be most abundant where for any cause there is some interruption in the regular flow of the current, as rapidly moving waters deposit much less readily than those whose movement is very slow."

consideration of the several rock formations, it is possible to form some idea of their relative importance as a possible source of ore minerals. It is now generally admitted that meteoric waters by descent to and contact with heated rock masses at great depths may be transformed to ascending waters; therefore, the minerals which constitute these ores, so far, at least, as their position relative to that of the ore bodies is concerned, may have had their origin either wholly or in part in any of the country rocks that remained uneroded at the time of ore deposition. The region was then presumably deeply buried by rocks now removed, consisting of small areas of the Algonkian and Cambrian, of the Ordovician and Carboniferous limestones, Minnelusa sandstones, and Cretaceous rocks, together with much intrusive porphyry, making in all an aggregate thickness of probably 4,000 feet. To these, as a possible source of ores, must be added Algonkian schists and their included eruptives to indefinite thicknesses below the level of the ore bodies. The ore minerals to be derived from these rocks are, in the relative order of their abundance, silica, pyrite, fluorite, wolframite, barite, tellurium, torbernite, gypsum, stibnite, gold, and silver.

For the silica, so many different sources can be suggested that its origin does not deserve special consideration. The same may be said, though in lesser degree, of the pyrite which, while present in considerable amount in the ores, is too widely distributed a mineral to have its origin exclusively in any of the country rocks.

The fluorite, perhaps more than any other mineral present, may be ascribed to pneumatolitic emanations from the eruptive rocks at the time of intrusion. Barium may have originated from small quantities in the feldspars of the igneous rocks, in which it is known to occur in considerable quantities. For the rarer elements, such as tungsten, tellurium, arsenic, antimony, and, in instances, uranium, no tests have been made. Since these minerals can not readily be supposed to have been original constituents of the sedimentary rocks, their origin must be sought in the Algonkian or eruptive masses. Wolframite occurs in considerable quantities in rocks of the Algonkian, associated with the tin deposits, both in Nigger Hill and in the southern hills. Its occurrence suggests that similar deposits and bodies of eruptive granite may exist below the schists in the vicinity of the tungsten deposits near Lead, and if so, they may readily be supposed to have supplied this mineral to ascending thermal waters. It is, of course, possible that tungsten also is present in the eruptive rocks, but if so, it is yet undetected. In the light of the evidence as to direction of flow of mineral solutions no such assumption is essential.

Arsenopyrite is known to occur in the auriferous lodes of the Algonkian (see description of Homestake ores, p. 68). Tellurium, arsenic, antimony, and uranium may have had their origin in either eruptive rocks, or Algonkian schists, but their presence in either is not reported.

Of the gold and silver contents of the various rock formations more is known. Among the sediments the only series which undoubtedly contained gold at the time of the ore formation is the Cambrian. This gold occurs, (1) in the form of auriferous conglomerates at the base of the Cambrian; (2) as small amounts of free gold widely disseminated through unaltered sediments, presumably contemporaneous with their deposition. Of this latter type of gold the writer has seen no occurrences in person, but many instances of the kind are reported, and as they originate from reliable sources, they are probably accurate.

That the schists of the Algonkian were mineralized with gold and silver prior to the deposition of the Cambrian, the study of the Homestake and other Algonkian deposits has placed beyond question. Many other instances of small quantities of gold at different places in the Algonkian series have come under the notice of the writer, although never in sufficient quantities, nor of high enough grade, to be of economic importance.

Whether gold and silver were original ingredients of the eruptive rocks, it is much more difficult to determine. These rocks frequently yield appreciable amounts of gold and silver on assay—a fact which is attested by a number of assays made for the writer, as well as by examination of assay returns from several mines. Such assays, however, were confined to eruptives so closely associated with areas of mineralization that these values may have been introduced into them at the time of ore deposition. It seems, however, possible that there may have been some small quantity of these metals in the original rock, although it can not be definitely proved.

It will be seen from these data that the country rocks of the ore-bearing areas contained at the time of the ore deposition most of the ore minerals in quantities sufficient to have constituted an adequate source of supply, and in the opinion of the writer, it is very probable that each of these rock divisions has contributed to the ore formation, one adding one element to circulating waters, and one another. How the metallic contents have been derived from these rocks—schists, sediments, and eruptives—whether exclusively through a leaching by purely meteoric waters, or by the additional aid of occluded moisture or gases released from eruptive magmas, it is not possible to say. The presence of such large quantities of fluorite in the ores certainly leads one to suppose that the latter action has been an important factor in the ore genesis and in the opinion of the writer it has had much closer connection with the origin of these ores than is generally admitted. It is further probable, since the ore deposition followed so closely the eruptive activity, that the heat imparted to mineral waters by igneous rocks served to increase in no small degree the activity of circulation.

METHODS OF TREATMENT.[a]

After the failure of the earlier attempts to treat these refractory siliceous ores by amalgamation, a plant for the treatment of the ores by chlorination was erected by the Golden Reward Company at Deadwood, in 1889, and a second plant of similar character was built at Pluma, in 1895, by the Kildonan Milling Company. This process was attended with a greater degree of success than any before tried, and until recently has been largely used. With the increase in the understanding of the chemical character of the ore other processes were found to make so much better saving of the precious metals that chlorination has now largely given place to them.

In 1892 a cyanide plant was built in Deadwood, but seems to have been in operation only intermittently. In 1890 the Deadwood and Delaware Smelting Company built the plant in Deadwood for the treatment of the ores by matte-smelting, and under the efficient management of Dr. F. R. Carpenter this method of treatment became one of the most successful that had yet been adopted. Since its erection the plant has been purchased by the Golden Reward Company and much enlarged. Another is now in process of construction at Rapid.

Within the last three years the cyanide process has been used with increasing success on these ores. The percentage of extraction is somewhat lower than that attained by smelting, but the saving in expense is so great that ores may often be profitably handled, even though of lower grade than those economically treated by other methods. There are now in operation in the Black Hills eight cyanide plants treating the refractory siliceous ores, while numbers of others are in process of construction.[b]

METHODS OF MINING.

The methods of mining followed in the siliceous ore regions are extremely simple. Shafts are not deep, and in many instances the ore outcrops so near the surface that the mining operations may be carried on by means of drifts. The loose, incoherent nature of the Cambrian rocks necessitates some timbering, but that is generally of a very simple character. Lagging is necessary in the larger stopes, owing to the lack of rigidity of the shales that often form the roof of the ore; but in the smaller shoots the entire ore body is frequently extracted without the use of supports of any kind. In much oxidized and decomposed

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[a] Detailed accounts of the treatment of the ores will be found as follows: F. R Carpenter, Trans. Am. Inst. Min. Eng , vol. 17, pp. 570–598. F. C. Smith, Trans. Am. Inst. Min. Eng., vol 27, pp. 422–426. Charles H. Fulton, Bull. No. 5, South Dakota School of Mines, February, 1902.

[b] Fulton, C. H , Bull. No 5, South Dakota School of Mines, p. 65, February, 1902.

areas more careful support of the roof is necessary. In a few mines difficulty has been experienced in handling the water, largely on account of the uneven and undulating character of the quartzite on which the ores occur, so that the location of a sump is never permanent, but must be shifted from time to time. In large bodies of ore the center of a shoot is generally removed first, pillars of ore being left to support the roof if the timbering itself is insufficient; the rims and, finally, the pillars are then removed, and all waste material in the ore is deposited in the center of the stope. Caving is sometimes resorted to after ore has been removed, and gangways left along the edges of shoots, the expense of maintaining a large amount of timbering being thus avoided.

Prospecting.—Mining property in the siliceous ore region is often sold without regard to ore "in sight," so that the method and intelligence with which systematic prospecting is carried on has an extremely important bearing on the profitable working of the ores. The first step is the determination of the ore-bearing beds. This having been decided, the beds are opened up by a shaft, if below the surface, or by tunnels if exposed; drifts are then run at right angles to the prevailing direction of ore shoots in the region. Verticals or ore bodies intersected are followed or mined out along their strike, and other crosscut drifts are run at considerable distances from and parallel to the first. In this way an exceedingly extensive area may be prospected for all except shoots of extremely small size at a nominal expense. Intrusive porphyries occasion some inconvenience, but this can generally be overcome by intelligent work. Mining companies that have kept their systematic prospecting in advance of their ore extraction have opened up new shoots before old ones were mined out, thus enabling them to produce continuously, while those companies that have not adopted this method have been subjected to an expensive and discouraging period of dead work and inaction when their ore "in sight" was exhausted.

FUTURE OF THE REFRACTORY SILICEOUS ORES.

While there are considerable tracts of the ore-bearing beds of the two known horizons still unprospected within the exposed rim of Cambrian strata above mentioned, the development of such ore bodies as may there be discovered can not maintain the production for any great length of time. But there are many included dolomite beds between the so-called lower and upper contacts which have been but little, if at all, explored, and which there is every reason to believe are mineralized. Upon the prospecting in these beds and the discoveries which exploration may make where ore-bearing beds are deeply buried beneath the overlying limestones of the Carboniferous will depend the future of this class of ores. It is therefore necessary to answer the question, How far in these directions does the mineralized area extend? This is a difficult question. Three conditions determine the occurrence of these ores: (1) The presence of the marbleized dolomite or ore-bearing beds; (2) fractures by means of which mineralizers may obtain access to such beds; (3) the percolation of mineralizing waters.

As before stated, it has been proved that the ore-bearing dolomite occurs under much of the limestone to the west of Portland, and the same beds have been detected far west of Spearfish Canyon, so that it is probable that the ore-bearing rock is uniformly present over extensive areas.

The presence of fractures is a condition which would also seem to be fulfilled, at least so far as the eastern side of Spearfish Canyon is concerned, for the occurrence of mineralized fractures in the limestone of Elk Mountain, Ragged Top, and Carbonate indicate that verticals may be likewise present in the Cambrian below.

The third and, perhaps, most essential condition, however, that there should have been mineralizing action upon these deeply buried strata is one which only development can determine. If we are to consider the Ragged Top ores, which are of the same general character as the majority of refractory siliceous ores, to be the work of ascending waters, then it is not improbable that these deeply buried beds have been mineralized; but as the evidence on this point is by no means conclusive no argument can be based on such an assumption. That refractory siliceous ores have been found in the Cleopatra mine in the bed of Squaw Creek and are also reported by Carpenter[a] from Cold Creek to the east may be taken as an indication of the future value of the region, and are certainly sufficient grounds for a careful and extensive prospecting. In general there does not seem to be any reason why ore bodies should not occur beneath the Carboniferous, and if they do this class of ores may continue to be an important factor in the gold production of the Black Hills for many years.

PYRITOUS ORES.

Under this head are included ores of gold that show usually a heavy pyritic content with which are sometimes associated other sulphides, such as sphalerite and galena. These ores occur at various points within the Spearfish quadrangle and have been intermittently mined, but, on account of the small size, irregular character, and low grade of the ore bodies, have never been an important factor in the gold production of the region.

Two Bit district.—The best-known occurrences of these gold-bearing pyrite ores are in Two Bit Gulch. The country rock is here Cambrian shale of varying thickness, consisting chiefly of fine gray shale, glauconitic in places; iron-stained, shaly sandstones sometimes calcareous in character; and some few layers of dolomitic breccia. Interbedded with these Cambrian strata are many sills of syenite-porphyry,

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[a] Trans. Am. Inst. Min. Eng., vol. 17, 1889, p. 570.

coarse rhyolite- or granite-porphyry and other varieties of eruptive rock. At the base of the Cambrian series is a heavy and much indurated quartzite, but at no point observed by the writer does the banded dolomite or characteristic horizon of the siliceous ores occur upon this quartzite.

The ore bodies generally are the result of mineralization along fractures or verticals which cut eruptives and Cambrian strata indiscriminately. The ores are composed largely of pyrite, which occurs in heavy, almost amorphous masses in the Cambrian shales on or near the basal quartzite, and is reported to have been in the form of shoots of considerable width in the Hardin mine. When fractures intersect porphyry the pyrite often occurs in crystalline druses and at times is scattered thickly through the body of the eruptive rock. The quartzite is also in places heavily impregnated with pyrite. This pyrite is reported to have yielded low values in gold, although no authoritative data as to the exact yield are available. As pyrite is essential to the smelting of the refractory siliceous ores it was hoped that these low-grade ores, if concentrated, might find a local market, but for some causes not well understood several trials proved them unsatisfactory. The Hardin shaft is the only mine in which bodies of pyrite of workable size have been found. Much ill-advised mining has been carried on in this district and, although in future these ores may possibly prove to be of value for smelting purposes should other sources of supply become unavailable, in the light of the present development operators would do well to exercise caution in their exploitation.

In their occurrence these ores show quite a strong resemblance to the refractory siliceous ores. The fracturing is of later age than the igneous activity and so also the pyritization. The mineralizing process seems to have been in the nature of a replacement by pyrite of a portion of the different rocks through which the fractures pass.

TUNGSTEN ORES.

WOLFRAMITE.

HISTORY.

For some years prior to 1899 large quantities of what was locally known as "black iron" were mined, together with refractory siliceous gold ore, from workings in the Lead and Yellow Creek siliceous-ore areas, as described on page 151. In most cases this material contained very low values in gold, and was sorted from the ore, so that it accumulated in considerable amount on the waste heaps of the mines. Some of that from Yellow Creek, however, is reported to have yielded workable gold values. This was shipped to the smelter and there treated among other basic ores without suspicion of its special value. In January, 1899, however, its great weight attracted the attention of a local mineral collector and a few simple tests served to reveal its true character. Its importance was quickly recognized by manufactures of tungsten steel, and the exploitation of the deposits has now developed into an industry which, although not extensive, has yielded considerable profits to individual owners.

OCCURRENCE OF THE WOLFRAMITE.

This mineral has been found thus far at two localities. The first is upon the Cambrian outlier immediately north of Lead, on the top of the high hill which forms the crest of the divide between Gold Run and Deadwood Gulch; the second is in the narrow tongue-like area of Cambrian which, as a thin capping on the divide between Yellow and Whitewood creeks, projects north into the central area of schists. The two lie in a line which trends about N. 25° to 30° W., and follows very closely the strike of the schistosity of the upturned metamorphic rocks below. In the latter rocks, just east of the northern deposits, are the open cuts of the Homestake mine, which lie in a line nearly parallel to that connecting the wolframite areas, and on a great mineralized, gold-bearing zone in the schists. The Yellow Creek occurrences lie just west of the projection of this zone, bearing the same relation.

As stated above the wolframite is found in much the same relations as the refractory siliceous ores already described.

It occurs in flat, horizontal but rather irregular masses up to 2 feet in thickness. They frequently cover considerable areas, of which perhaps the largest so far discovered may have an extent of 20 to 30 square feet; but they are so extremely irregular that it is difficult to form an exact estimate of their lateral extent. These masses lie upon or near the basal quartzite of the Cambrian or where that is absent upon the conglomerate that separates the upper members of the series from the rocks of the Algonkian. The beds in which it lies are an impure dolomite sometimes so full of sand grains as to grade into quartzite—a fact that has not infrequently given rise to the erroneous opinion that the ores are mineralized quartzite.

Above the dolomitic beds generally occur layers of shale, which become much more argillaceous, and often contain considerable glauconite, as one passes vertically upward. Above these shales, both in the vicinity of Lead and Yellow Creek, are found remnants of a rhyolite sheet, showing in many cases a well-developed columnar structure.

The wolframite is to be considered more in the nature of a basic phase of the refractory siliceous ores than as a separate and distinct deposit, for it occurs always in intimate association with them. At times it forms a rim around the outer edge of the siliceous ore shoots, often extending inward and upward so as to form a thin capping to that ore. It thus appears as a sort of envelope to the siliceous-ore mass, which it incloses, or nearly incloses, on all except the lower side. Margins of this kind are often from 2 to 2½ feet thick, but the capping portion is generally thinner. At other times the wolframite occurs in irregular masses, scattered through the siliceous ore, or in stringers and thin, contorted layers in the partially silicified dolomite. In the Wasp No. 2 mine, in Yellow Creek, it was observed in lenticular or kidney-shaped masses in the shaly dolomite. An excellent instance of the first or envelope type of occurrence is to be seen in the Harrison mine, near Lead. In the Two Strike mine in the Yellow Creek area it was seen in thin, irregular layers replacing the uppermost and more calcareous portion of the basal Cambrian quartzite.

In general the ore is separated from the nonmineralized rock by a fairly sharp line of demarcation; but in not a few cases it grades off so that the ore becomes leaner and passes by scarcely perceptible transitions into the country rock. In almost all cases considerable silicification has extended beyond the wolframite deposition so that, without the aid of the microscope, it is difficult to distinguish the original rock from quartzite.

CHARACTER OF WOLFRAMITE ORE.

As taken from the mines, the wolframite is a dense, black, massive rock of fine, granular texture and great weight. It closely resembles a fine-grained magnetite; but its greater specific gravity and slightly brownish streak, together with the associated minerals, generally render its identification possible. The component grains are, in the majority of cases, about one thirty-second inch in diameter, and always exhibit brilliant cleavage faces. In the portions having coarser texture, the grains are one-eighth to one-fourth inch across, and have slightly curved surfaces with an extremely brilliant metallic luster. They do not possess crystalline boundaries except when the replacement has been but partial or when crystals project into cavities. Radiating aggregates or single tabular crystals of barite are present in considerable abundance embedded in the body of the wolframite, but are more sparsely distributed in the more massive portions. They have always attained a perfect crystalline development, which shows that they are the earlier formed ingredients of the ore. Irregular cavities or vugs, such as are generally to be seen in deposits originating from the replacement of one mineral by another, are present throughout the ore in great numbers. These are of all sizes, some of them very intricate in form, and often of considerable aggregate volume. Their interior surfaces are usually coated with small but well-formed crystals of wolframite, not unlike marcasite in their form and in the manner of their grouping, and with crystal druses of yellowish or bright-green scheelite. The crystals of the latter mineral are often of great beauty and perfection. In some cases, cavities are filled with white or glassy crystals of barite. In a few instances, the leaner wolframite from Yellow Creek shows long, slender crystals of stibnite, radiating from a common center, much in the manner of the spicules of a radiolarian.

Despite the decomposed and gouge-like character of the country rock, alteration has not generally taken place to any noticeable degree. When the ore has been long exposed to atmospheric conditions, however, a mineral of gold-yellow color, in glistening druses of extremely minute crystals, very often coats the surface. This has been considered by Forsyth[a] as suggestive of tungstite, or tungsten trioxide; but none of that collected by the writer gave satisfactory results to tests for tungsten, and its true character has not yet been determined.

Under the microscope the ore, when very pure, shows little besides the dense, opaque wolframite. Occasionally, interstitial masses of clear, glassy quartz are observed, filling the spaces formed by the crystal faces of wolframite. When sufficiently lean to permit the use of transmitted light, however, the wolframite may be seen to be made up of innumerable small crystals, which are generally well developed, but interfere with one another at their extremities. There are thus left between the wolframite individuals many irregular spaces, always bounded by plane surfaces and usually filled, either with secondary quartz or by grains of original detrital quartz, about which enlargements caused by later added silica have formed complete crystals. In some specimens large crystals of barite are to be seen. Scheelite occurs interstitial to the wolframite. Sections of the ore cut from the portion where it passes into the unreplaced rock show a moderately abrupt transition from massive wolframite to partially replaced material, with interlocking crystals, which gradually become more sparsely scattered, until they finally disappear in the barren rock. The latter is generally heavily silicified beyond the limits of the wolframite, so that the microscope shows, if polarized light be used, that the rock is almost wholly composed of silica. If, however, the polarizer be removed, nothing can be seen but the sharp outlines of irregular rhombs, such as constitute the body of the usual type of dolomite before mineralization, the original carbonate having been replaced with such delicacy that its structure has been perfectly preserved.

CHEMISTRY.

The following analyses were made by Mr. W. F. Hillebrand in the laboratory of the United States Geological Survey. Both analyses are of specimens of the purer and more massive portions of the wolframite. No. I is of a specimen taken from the Two Strike mine in Yellow Creek. It is complete, and may be assumed to show the average composition of the wolframite. No. II is a speci-

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[a] Black Hills Mining Review, vol. 5, No. 32, pp. 14, 15.

men from the Harrison mine, near Lead. It is, only partial, but is inserted to show the relatively high percentage of lime.

Analyses of wolframite ore.

	I.	II.
	Per cent.	*Per cent*
SiO_2	12.87	9.60
WO_3	61.50	61.70
Fe_2O_3	3.85	[a] 12.67
FeO	9.18	....
Al_2O_3	.52	....
MnO	8.21	7.21
CaO	.93	5.39
SrO	.02	....
BaO	.04	....
$K_2O+Na_2O+Li_2O$	.08	....
H_2O, below 105° C	.20	....
H_2O, above 105° C	.87	....
As_2O_5	1.25	....
P_2O_5	.12	....
V_2O_5	Trace.	[b] .10
S or SO_3	Trace.	....
Total	99.64	....

[a] Determined as Fe_2O_3, includes FeO.

[b] Approximate

Assays of I.—Gold, 0.05 oz. per ton; silver, 0.25 oz. per ton.

Extremely minute traces of Mg, Zn, Cu, Sb, and Sn were also found.

While it is not possible to calculate from these analyses the exact mineral composition of the ore, on account of the difficulty of determining the form in which the minor ingredients are present, the relative proportions of the more important constituents may be roughly calculated as follows:

Proportions of principal minerals.

	I.	II.
	Per cent.	*Per cent.*
Wolframite (FeMn) WO_4	75.60	51.58
Quartz, SiO_2	12.54	9.60
Scheelite, $CaWO_4$	4.77	27.68
Barite, $BaSO_4$	.06	....
Ferric oxide, Fe_2O_3	3.85	....
Water, H_2O	.20	....
Arsenic oxide	1.25	....
Residual clay (kaolin)	1.34	....

It will at once appear from these tables that the ore is contaminated chiefly by scheelite and quartz. The first has probably been formed by the combination of some of the tungstic acid with the original lime of the mineralized beds, while the silica may have been either a portion of the unreplaced quartz, which occurs in grains throughout the country rock, or later formed silica, introduced at the time of mineralization.

For metallurgical purposes it is probable that the minor constituents, such as arsenic, vanadium, and especially phosphorus, may seriously impair the utility of the ore. Analysis No. II is interesting as showing a relatively large proportion of scheelite.

CONCENTRATION.

As only the purer and more massive ore carries a sufficiently high percentage of tungstic acid to meet the requirements of the smelters, it has been found necessary to concentrate a considerable portion of the material mined. At some of the mines the crude method of hand sorting and trimming off of gangue by hammers is adopted. For this purpose a considerable number of men must be employed and the cost must be heavy; but the value of the ore seems to justify even this expense. Of late, experiments have been made with various wet methods of concentration; and Forsyth[a] discusses in some detail the several processes which have been tried. He shows that the chief difficulty lies in the production of slimes, and that, in cases where considerable gold values occur in the ore, they pass into the concentrates and not into the tailings. This difficulty is, however, of minor importance, as the ore rarely carries any appreciable amount of precious metals. At the time that the mines were visited it was suggested that these ores, which are quite strongly magnetic, might readily be separated by the Wetherill concentrator; and in the opinion of the writer the difficulties that have been encountered might thus be obviated. It will be interesting to note the result of such experiments.

VALUE.

The Mineral Industry for 1899 shows that the tungsten market is a somewhat fluctuating one, and it is not therefore possible to give any exact idea of the value of the ore; but it is reported to have been sold at from $100 to $250 per ton according to the percentage of tungstic acid present and the date of sale.[b]

DISCUSSION.

Wolframite is not a common mineral, and its occurrence in bodies of sufficient size to be profitably worked is rare. Deposits have been found recently in Arizona and Nevada and at a few other localities in the United States.[c]

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[a] Black Hills Mining Review, vol. 5, p. 15.

[b] Ibid., p. 15.

[c] A very comprehensive summary of the tungsten deposits of the United States may be found in the volume of the U. S. Geol. Survey on Mineral Resources for 1899–1900, pp. 300–304.

So far as the writer has been able to determine, the associations in which wolframite ores are found are two:

1. As a constituent of pegmatitic granites, usually of the type known as greisen, and frequently more or less closely associated with ores of tin. Such deposits occur in the Black Hills in the Nigger Hill and Etta tin districts, but the material is there crystalline, and is generally believed to have resulted from pneumatolitic action.

2. In quartz veins, in granite or other rock of related character. Most of the more recent discoveries belong in this class; for instance, those in the Dragoon Mountains of Arizona; at Murray, Shoshone County, Idaho; Osceola, Nev.; San Juan County, Colo.; etc.[a]

The familiar case of the wolframite of the Cornwall tin region is in part comparable with both of these types.

It will at once appear that neither of these two classes of deposits bears any resemblance to those under discussion, and it is evident from the manner in which the ore occurs that it is to be ascribed to the same mineralizing agencies as the deposition of the siliceous ores. The association of the latter with fractures, the occurrence in an easily replaced rock, and the manner in which original structures have been preserved in the ore have been shown to prove that they are due to the replacement of carbonates by siliceous material. In the case of the wolframite there seems no reason to doubt that the same series of events has taken place, although a partial replacement of quartz may have occurred at the same time. First there was a fracturing of the country rock, then the replacing action of mineralizing waters which gained access to the replaceable strata by means of the fractures, and finally a gradual interchange of carbonate (and possibly of some quartz) for wolframite, molecule by molecule.

LEAD AND SILVER ORES.

LEAD-SILVER ORES OF GALENA AND VICINITY.

The greater part of the data upon which the discussion of these ores—at least, in the vicinity of Galena—is based is taken from the field notes of Mr. G. W. Tower, formerly of the United States Geological Survey. The writer has merely assembled Mr. Tower's descriptions and formed from them the generalized statements that follow.

The lead-silver ores of Galena and vicinity once filled an important place in the mineral production of the northern Black Hills. About twenty years ago a smelter was in operation, and several mines were producing heavily, the Richmond or Sitting Bull mine especially having figured quite prominently in the silver production. Smith[b] gives the total output as "little short of $750,000."

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[a] Mineral Resources, 1899-1900, pp. 300-304.

[b] Trans. Am. Inst. Min. Eng., vol. 27, p. 427.

After a brief period of activity, however, operations were rather abruptly discontinued, and the district was idle until the year 1896, when operations were resumed, although upon a somewhat smaller scale. Work is now being conducted in rather a desultory manner.

Mines that have produced this character of ore are situated in and about the town of Galena, most, if not all, of them being upon ore bodies that occur in strata of Cambrian age.

In order of their importance, the principal producing mines are as follows: Richmond (Sitting Bull), Florence, Hester A., Coletta, Merit No. 2, Cora, Carpenter, Alexander, Romeo, El Refugio, and Washington.

The ore that occurs in these mines is as a whole of a much more basic character than any found in the more westerly ore deposits heretofore described. When unoxidized it consists chiefly of pyrite, which is either massive or more frequently disseminated through the body of the country rock. With the pyrite is associated argentiferous galena and not infrequently small quantities of sphalerite. In many cases the galena occurs in seams in the pyrite or as druses of minute crystals lining the interiors of cavities. In all cases where found unoxidized these two minerals are associated in this manner. The galena is, therefore, of later origin than the pyrite. Occasionally the latter carries low values in gold, but these are unimportant, the values that render the mines workable being contained in argentiferous galena. In most cases there is but little silica associated with the ores, but in the Florence and Richmond (Sitting Bull) considerable amounts of secondary silica are found in intimate association with the deposits. In such cases the body of the ore is composed largely of secondary silica and pyrite and resembles in the mode of its occurrence the refractory siliceous ores. Through the silicified material are scattered irregular bunches and stringers of argentiferous galena and pyrite, but the relations of the two can not be definitely determined. The sphalerite is not an essential ingredient, but occurs at times in small amounts. The ore lies in shoots or long lenticular bodies of varying thickness or width. These follow vertical fractures which traverse the Cambrian strata and the intruded porphyry bodies indiscriminately. They sometimes strike in a single direction; at others, form several intersecting systems. The trends of the fractures are usually constant within any single mineralized area. Displacement along the fractures is generally very small, but in some cases throws of as much as 4 feet are observed. The shoots vary in width from scarcely perceptible seams to flat bodies as much as 20 feet wide; the thickness is generally from a few inches to 2 feet, though in some instances it is as much as 4 feet. When the fractures are open the ore generally fills the intervening space. The rock in which the ore occurs is either a quartzite containing considerable calcite as a cement to the sand grains or a shaly limestone that is presumably dolomitic. The ore bodies usually lie in the uppermost layers of these ore-bearing beds and immediately beneath a capping shale, the fractures sometimes extending beyond the shale beds and sometimes terminating in them. This ore-bearing rock in the Florence and Richmond, El Refugio, and Alexander mines is about 300 feet above the Algonkian, presumably near the top of the Cambrian series. In the Carpenter and Washington the ore-bearing rock is about 100 feet above the schists and is an impure and sandy limestone; in the Merit No. 2, Cora, Hester A., Horseshoe, Comet, and Romeo it is a calcareous quartzite at or near the base of the Cambrian and not more than 30 feet above the Algonkian schists.

The lead-silver values in these ores are very unevenly distributed. Much of the ore from the Sitting Bull mine was rich, containing 2,000 ounces of silver per ton, but generally the grade was very much lower and considerable quantities of the ore yielded only 6 or 8 ounces per ton.

In the mode of their occurrence these sulphide deposits bear a strong resemblance to the refractory siliceous ores, but are of much more basic composition. Both occur in the form of shoots which follow vertical fractures and constitute chiefly replacements of the calcium and magnesium carbonates of the country rock. It is, however, probable that the replacement in case of these more basic ores has not been entirely confined to these more readily soluble constituents. While the oxidized condition of most of these ore bodies renders it difficult to obtain evidence on this point, it is not improbable that a considerable portion of the quartz in the country rock has been replaced by pyrite and galena.

Age of the mineralization.—The fractures along which the ore deposition has taken place cut the eruptives, and fillings of sulphide frequently extend into the porphyries. The mineralization is, therefore, subsequent to their intrusion.

CHAPTER III.

ORES IN CARBONIFEROUS ROCKS.

The gray limestone of the Carboniferous carries two distinct varieties of ore: (1) Ores of gold and silver; (2) ores of lead and silver. The latter class of ores was in past years of very considerable importance, but the single locality from which they were obtained has long since been worked out and they are now chiefly of historical interest. The gold and silver ores are of the refractory type and of comparatively recent discovery, but they are of small size and of minor importance. In general the Carboniferous rocks have not figured largely in the mineral production of the region.

GOLD AND SILVER ORES.

As stated above, these ores are of the refractory siliceous type. They include the deposits found in the vicinity of Ragged Top Mountain and a small prospect found in the neighborhood of Galena.

RAGGED TOP DISTRICT.

West of the elevated region, about Crown Hill and Portland, is a broad, flat, plateau into which streams have incised deep canyons with abrupt, precipitous walls. This plateau is formed by the thick, massive strata of gray Carboniferous limestone which extend with a slight northerly and westerly dip as far west as the edge of Spearfish Creek, being then cut through to the underlying Cambrian by the deep and precipitous gorge through which the waters of that creek find egress to the surrounding lowlands. Just east of this canyon there rises from that portion of the limestone plateau that lies between the two forks of Calamity Gulch and the low, rounded dome of Ragged Top Mountain, a laccolith of phonolite intruded at the base of the Carboniferous formation, and now exposed above the surrounding country by the erosion of the uplifted covering. In the flat limestone that surrounds this phonolite mass are the ore bodies, upon the strength of whose discovery the towns of Balmoral, Preston, and Ragged Top were built. It was formerly thought that these limestones would yield only lead-silver ores similar to those found about 4 miles north at Carbonate, but in 1896 a miner named Wall made the accidental discovery of rich ores of gold occuring as irregular bowlders of silicified limestone upon these limestone flats. A typical mining excitement followed and a rush of prospectors to the region caused the rapid growth of the above-named towns.

The mines that have yielded ore are the Dacy group, the Ulster, the Pete Hand prospect, and some small mines on the southern slope of Elk Mountain.

DACY GROUP.

The Dacy group comprises a series of seven nearly equally spaced vertical fractures just north of Ragged Top Mountain and separated from it by Jackass Gulch. Taking them up from east to west they have the following strikes: N. 50° E., N. 52° E., N. 37° E., N. 58° E., N. 36° E., and N. 59° E. The seventh is of comparatively small importance. Numbers of small fractures of comparatively insignificant size were also observed. Pl. XVII (p. 214) gives an idea of the relation of these fractures to the geology.

These fissures are of various widths at the surface, a maximum being about 10 feet, from which they range down to extremely minute crevices. In the lower portions, where surface alteration has not been extensive, the ore can be observed to pass laterally into the limestone walls without disturbing the structure of the latter rock. It is of a uniform light-buff tint which is so nearly the color of the surrounding limestone and so perfectly preserves the structure that by the eye alone it can be distinguished from the unmineralized country rock only by superior hardness and slight yellow tinge. Nevertheless the lines of demarcation at either side of the ore body, if examined closely, are sharp and somewhat undulating. The mineralized zone generally narrows downward so that at a maximum depth of about 60 feet(?) the ore bodies are represented by mere streaks.

The ore when followed up to the surface becomes more and more bowlder-like and broken on account of the irregular manner in which the disintegration has occurred. The gossan itself is composed of large irregular bowlders of extremely hard siliceous material, stained red and brown by iron oxide, and composed of brecciated and irregular fragments of limestone, now wholly altered to silica and containing many sharply angular cavities lined with druses of quartz crystals. Cavities containing calcite crystals are not infrequently encountered, but occur, so far as known, in the poorer quality of ore. These bowlders are grouped in linear arrangement so that they outline the position of the fissure.

Much of the ore is composed of angular brecciated fragments of what was formerly limestone, but has been wholly altered to silica. The ore bears strong resemblances to the brecciated limestone that is found at many points in the Carboniferous areas where there have been dynamic disturbances but no mineralization. Many fine thread-like crevices, stained by a peculiar pinkish-brown oxide, in addition to the silicification, have been found associated with these ores. All of this was formerly supposed to be iron oxide, but considering the large amount of tellurium present in the ores it is not improbable that it may contain an oxide of that metal.

MICROSCOPIC APPEARANCE.

Examined under the microscope the ore is found to consist chiefly of secondary quartz in irregularly bounded individuals, which do not show crystalline boundaries except where open spaces have allowed their formation. A little opaline silica is also present. The yellow color seems to be due to the presence of a uniformly distributed pinkish-brown pigment, which is spread between the grains of quartz in such thin films that its character can not be definitely determined. Some of the richest portions of the ore show excessively minute opaque particles, that may be metallic. In one specimen of ore, carrying \$3.05 per ton, a small speck of metallic mineral resembling sylvanite was detected, but in general tellurides, if present, have been completely oxidized.

CHEMICAL CHARACTER.

Two analyses are given below. No. I was taken from the paper by F. C. Smith.[a] No. II was made by W. F. Hillebrand in the laboratory of the United States Geological Survey.

	I.	II.
	Per cent.	*Per cent.*
SiO_2	90.990	96.27
Al_2O_3	2.970	.26
Fe_2O_3		.26
FeO	3.024	.19
MgO	Trace.	.19
CaO	1.138	1.16
BaO	Not det.	.06
Na_2O	Not det.	.05
K_2O	Not det.	.11
Li_2O	Not det.	Strong trace.
$H_2O-105°$	.110	.03
$H_2O+105°$		.42
CO_2		.96
Volatile matter	.802	
S	Not det.	.05
Au	[b].053	[c].06
Ag	[b].003	[c].02
Te	[b].091	[d].03
Total	99.181	100.12

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[a] Trans. Am. Inst. Min. Eng., vol. 27, p. 418.

[b] The writer has taken the liberty of calculating out the percentages of Au., Ag., and Te, given by Professor Smith in ounces, and adding them to the same total.

[c] Direct determination.

[d] Perhaps low.

By assay (ounces per ton of 2,000 pounds).

	I.	II.
Te	29.26	
Au	17.34	15.25
Ag	1.21	4.75

The silica will be at once seen to constitute almost the entire body of the rock, only a small amount of calcium and magnesium remaining unreplaced. The alumina probably represents some original impurities in the replaced limestone, as also the soda, potash, and lithia. The volatile matter in analysis No. I is probably equivalent to the CO_2 in No. II, the latter ingredient resulting from a small amount of carbonates in the ore. It seems probable that the iron in No. I is not all ferrous, but some should be given as ferric iron. It is customary in the analyses of these ores, which are made for commercial purposes, to calculate all the iron as ferrous. The alkalies were probably contained in the original limestone and the small amount of barium may have existed in that rock or have been introduced at the time of mineralization.

At the foot of analysis No. I in the paper on these ores Professor Smith makes the following statement:

> Combining the gold, silver, and tellurium in the above analysis we find them existing in the following relative percentages:
>
> | | Per cent. |
> |---|---|
> | Tellurium | 61.20 |
> | Gold | 36.27 |
> | Silver | 2.53 |
> | Total | 100.00 |
>
> This closely approximates the composition of sylvanite according to Klaproth's analysis.

It will be noticed that in Analysis II the proportions are different, the percentage of silver being greater and that of tellurium relatively low. Some of the tellurium may, however, have been removed during the process of alteration. The sulphur shown in Analysis II may perhaps be combined with a portion of the ferrous iron in the form of pyrite.

On the whole the presence of tellurium in these ores seems to offer the most plausible explanation of their refractory character, and in the light of present knowledge it is not easy to suggest any other cause that will account for the difficulty of treatment.

METALLIC STREAK MINE.

This mine is situated on the southwest side of Ragged Top Mountain, just across Calamity Gulch, on the top of the limestone plateau. It comprises a series of shallow diggings from which are quarried flat bodies of red-stained limestone that are reported to carry as high as $10 to $25 per ton in gold. Associated with this ore are certain irregular patches of siliceous material resembling the Ragged Top ores in many respects, but carrying less gold, and often heavily impregnated with purple fluorite. The latter material also occurs in dense, sandy masses and in general does not carry much gold. In a few cases there are masses of brecciated material parallel with the bedding, cemented by brown-stained silica. The deposits are small and irregular and now so decomposed that their relations can not be readily appreciated.

ULSTER MINE.

The Ulster mine is situated on the north side of Long Valley about one-third of a mile north from the town of Preston. The country rock is Carboniferous limestone. A little north of the mine is an irregular hill composed of eruptive rock, while the mine is also intimately associated with irregularly intruded masses of rhyolite and phonolite. The ore occurs as irregular masses of silicified limestone with which are associated quantities of brilliant purple fluorite. These masses are generally in the limestone at the contact of that rock with irregular bodies of porphyry. The porphyry is often so decomposed as to be little more than soft clay. The portion containing fluorite is usually lower in gold than other parts of the rock, and the highest values are contained in the dark-colored silicified limestone. Much of the ore from this mine carried very high values, some of it yielding as much as $2,000 per ton in gold. The greater part of the ore was taken from surface workings and from a large number of shallow shafts, but the conditions are now such that but little can be made of the general relations of the ore.

Irregular bodies of silicified limestone have been found at many localities at various points on this limestone plateau, both northward as far as the junction of Spearfish and Squaw creeks, and southward to a point south of the Burlington and Missouri River Railroad. Many of them, such as the Pete Hand prospect, carry a moderate amount of gold, but none at present writing sufficient to admit of mining operation.

ORIGIN OF THE ORES.

The general character of the ores is such that they may be readily seen to be replacements of limestone by silica and fluorite with small quantities of gold, silver, and tellurium. Whenever sufficiently exposed to admit of observation they are associated with fractures which, in the case of Ragged Top deposits, have been traced downward for more than 300 feet. If it is assumed that the deposits were formed by ascending solutions the differing lithologic conditions will account for their difference from the siliceous ore bodies, which is chiefly one of form. The country rock here is a massive, homogeneous limestone in which there seems to be nothing that would favor a concentration of ore at any particular horizon, whereas, in the Cambrian deposits, there have been impervious shale beds or sheets of porphyry which have caused the mineralization to spread out away from the verticals at definite horizons.

LEAD AND SILVER ORES.

CARBONATE DISTRICT.

On the north side of Squaw Creek, near the point where it enters Spearfish Canyon, is the town of Carbonate. This was a flourishing camp in 1886 and produced considerable silver and lead. A smelter was built and during a number of years was in active operation. The production of the Iron Hill mine, the largest and most important mine in the district, is given below. It is probable that considerable ore was produced by other mines which were active from time to time. For the years 1889 and 1890 no output is reported, and it is probable that the mine was idle during that period, although the writer could obtain no definite information on that point.

Production of Iron Hill mine, Carbonate camp.

1885	$13,394
1886	372,120
1887	259,942
1888	15,000
1891	6,762
Total	667,218

The country rock that carries the ore in the Iron Hill mine is the gray Carboniferous limestone in which sills, dikes, and irregular masses of porphyry have been intruded. The ore bodies are of two kinds: large, irregular bodies of lead carbonate, which pass in places into more or less unaltered galena, generally in close contact with porphyry masses; and partially filled crevices which resemble in a general way the verticals of Ragged Top described on page 173.

The first type of deposit is that which has formed the chief source of silver in the district, and silver, as shown above, was largely obtained from the Iron Hill mine. In this mine the ore was a large mass of argentiferous lead carbonate which extended down for 300 feet on the east side of a thick dike of fine-grained white porphyry. Much galena was also found together with the carbonates, and after the ore was worked out a seam or vertical was detected extending downward from the main mass. Other pockets of ore were also found at different points, and in one place a pocket of vanadinite containing 4 or 5 tons was encountered. Mr. Fowler reports the occurrence of the following minerals: Galena, cerussite, cerargyrite, matlockite, wulfenite, pyromorphite, plattnerite, atacamite, and vanadinite. This type of ore resembles in its general character and in its association with porphyry bodies, the deposits described by Mr. S. F. Emmons, from Leadville, Colo.[a] Too little is known, however, regarding the details of the ore occurrence to afford any more definite idea of the manner in which it originated than the simple fact that it is probably a replacement of the limestone.

Of the second type of occurrence the most important case is that at the Seabury mine. This consists of an irregular crevice striking S. 85° W. and running through the Seabury, Iron Hill, Segregated Iron Hill, and Adelphi mines with a possible continuation in the Spanish R, a mine in which some ore was obtained but at too great a distance for its relation to the others to be clearly made out. This crevice varies from 1 to 20 feet in width. The sides consist of a ferruginous jasperoid material which replaces the limestone often for 2 or 3 feet from the crevice and contains at times galena, lead carbonates, and cerargyrite in sufficient amount to be profitably worked. Cerargyrite most frequently occurs as a thin film covering druses of fine quartz crystals which form linings to cavities.

The center of the crevice was loosely filled by a soft, ferruginous, gouge-like pinkish-red matter containing gold. A large quantity of this ore is reported to have been mined from the Seabury, and also from the west side of the porphyry dike in the Iron Hill.

To the north of the Seabury mine is a series of shafts situated along a line which strikes N. 74° W. These are the Far West, Rattler, Enterprise, Wilkerson, and Hartshorn shafts. None of them are now accessible, but they are reported to have been sunk on a second crevice of similar character to that just described. Only small amounts of ore were obtained from these workings. Numerous other small iron-stained seams or partially opened crevices may be observed in different places on the surface, but they do not seem to have been productive.

Since 1891 there seems to have been but little work done in this district, no output being recorded for that period. Within the last year, however, a small 35-ton cyanide plant has been erected to treat the tailings from the old smelter.[b]

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[a] Emmons, S. F., Geology and Mining Industry of Leadville, Colo.: Mon. U. S. Geol. Survey, vol. 12, p. 886.

[b] Fulton, C. H., Bull. South Dakota School of Mines No. 5, p. 65.

CHAPTER IV.

ORE DEPOSITS IN ROCKS OF RECENT ORIGIN.

PLACER DEPOSITS.

At many points throughout the hills auriferous gravels of comparatively recent origin have been worked, and constituted in early days the most important source of gold in the region. Here, as in many mining districts, their discovery evidently led to that of the large and more permanent lodes. Nearly all of the large gulches that lie well within the Black Hills uplift contain gold in some quantity, but it is chiefly those that head up in the areas of Algonkian rocks that have yielded large returns. The productive placers have been found in greater numbers in the southern portion of the hills than in the northern, but of those in the latter region the famous Deadwood placer and Nigger Hill placers have been important. The gold in these placers is all derived originally from the Algonkian rocks, for as the siliceous ores contain free gold only in rare instances it is not probable that they have added to the placer gold derived from other sources. The great comparative richness of the Deadwood placer has been shown by Devereux to be the result of a double concentration—first, in the formation of the fossil placers or cement deposits at the base of the Cambrian, and, later, in the sorting of the material derived by their disintegration. The Nigger Hill placers are comparatively small but numerous and have yielded rich returns for the area mined. When the gold from these ores is panned it is found to be mingled with great quantities of tourmaline and cassiterite and innumerable small red garnets, typical minerals of the Algonkian rocks, while to many of the nuggets and grains of gold are found attached fragments of glassy quartz, and in a few cases flakes and small masses of talcose-schist. Some speculation has taken place regarding the richness of the lode from which the placers of the Nigger Hill region seem to have originated and prospectors have been at considerable loss to explain the continued failure to find the mother lodes. It is well, however, to bear in mind that nature is a natural concentrator and that rich placers may readily have been derived from quartz ledges in which the gold was so sparsely distributed as to offer no encouragement to the prospector. The continued action of erosive agencies through great geological ages by operating on great quantities of material has concentrated the nuggets of gold and made them easily accessible to the miner, when in their original condition they may have been separated by so great areas of barren rock as to admit of no mining operations. In general the placers are not now productive. Many of those worked out are still yielding very small quantities of gold and enable some of the poorer miners to earn a livelihood, but as a factor in the mineral wealth of the hills their importance is largely historical.

CHAPTER V.

DETAILED DESCRIPTIONS OF MINES.

This chapter is designed to include detailed descriptions of mines which have not been separately treated in the previous pages. The mines have been grouped together comformably with the general arrangement of the paper; that is, basal Cambrian conglomerates are first treated, and then the refractory siliceous ores. As the mines working upon the other types of deposits are but few in number, their descriptions have been given with their general discussion and are not repeated here.

MINES IN AURIFEROUS CAMBRIAN CONGLOMERATE.

These mines are situated in the vicinity of Lead on the gold-bearing conglomerates at the base of the Cambrian series, isolated remnants of which lie on the tops of hills of schist, such hills forming an old Algonkian surface which dips in a general way eastward from the Homestake outcrop.

There are five productive areas, all but one of which are located on the east side of the Homestake lode. The remaining one is on the hill between the Homestake open cut and Poorman Gulch.

Beginning on the north the following mines have been worked on the four areas to the east of the Homestake (see Pl. VI). On the north side of Blacktail Gulch, beneath the heavy cap of rhyolite, the Minerva and Deadbroke mines have opened up a large area of gold-bearing gravel. These mines have been described on pages 106–110. Between Blacktail and Hidden Treasure gulches are the Baltimore and Deadwood, Esmerelda, and Hidden Treasure mines. These are now inaccessible. On the area next south, which lies on the crest of the divide between Blacktail and Deadwood gulches, are the Pinney open cut, Omega, and Deadwood-Terra mines. The first two are described below and the third was not visited.

About 1,600 feet southeast of the last-named area, beneath the thick cap of rhyolite which forms the top of a high hill just east of the Caledonia open cut, are the Hawkeye-Pluma, Gentle Annie, and Monitor mines, which have opened up a large area of gold-bearing conglomerate. These three mines, the Monitor in particular, have been very important producers, and they are described in detail below.

On the west side of the Homestake lode, between the Homestake open cut and Poorman Gulch, is the remaining area which was worked by the Durango and Harrison mines. Descriptions of these mines will be found on page 105.

Pinney open cut.—This is the most northeasterly of the 3 mines operated on a small area of conglomerate occupying the divide between Deadwood and Bobtail gulches. It is located on the extreme north end of a small spur, hence just east of the buried outcrop of the Homestake lode. It was one of the earliest opened mines of gold-bearing conglomerate in the region and yielded much rich ore, all highly oxidized. White quartz in the nature of broken ledge matter is said to have been mined from here, yielding very rich returns.

Omega mine.—Southeast of Pinney open cut are the workings of the Omega mine. A tunnel runs west fron the upper Terraville road through Algonkian schists and the ore is mined through raises into the conglomerate above. The conglomerate is about 12 feet thick and lies under a roof of friable, shaly sands. The stopes of the old mine are largely caved. The conglomerate was oxidized and contained a great number of fragments of schists of somewhat angular character; the remaining material was oxide of iron. Lenticular masses of quartz were encountered in the schist. They strike northwest and dip east, and are said to carry free gold in workable amount. They are supposed to be small veins parallel to the main Homestake ore body. The value of the ore in the Omega mine is reported by the management to be $6 per ton, of which $1.80 to $2 can be saved by amalgamation. The rest is refractory and can only be extracted by cyaniding.

MONITOR, GENTLE ANNIE, AND HAWKEYE-PLUMA MINES.

These three mines open up the area of gold-bearing conglomerate that lies beneath the heavy porphyry cap on the hill east of the Caledonia ore body. The floor of this area slopes sharply east away from the summit of the hill.

Monitor.—The most northerly of these three, the Monitor, is opened by a tunnel at the head of the South Fork of Bobtail Gulch. The tunnel extends southeastward and the workings run east and south so as almost to connect with those of the Gentle Annie and Hawkeye-Pluma mines. The tunnel which opens up the mine is in the Algonkian schist some distance below the conglomerate outcrop. It passes southeastward through schist into a large basin-like mass of conglomerate in which great chambers, often 20 feet high and 100 feet wide, have been excavated. The roof is a friable, cross-bedded sand, often loosely coherent and interrupted by bands of a finer texture composed of sand, scales of mica, and argillaceous material. In the roof is a series of iron-stained fractures following many different directions and intersecting one another. Some of these can be traced down into the ore, where they become lost among the pebbles of the conglomerate. The latter contains many very large bowlders and numerous fragments of schist. It is cemented by oxide of iron, but in many places this passes gradually into a matrix of pyrite. Where the workings approach those of the Pluma mine little or no oxidation has taken place and the quartz pebbles are embedded in a solid pyritic matrix sometimes showing cavities lined with druses of the same mineral. The conglomerate is frequently interrupted by interbedded layers of quartzite.

Gentle Annie.—The workings of this mine are situated east and slightly north of those of the Monitor. They are opened by a tunnel at the head of the gulch next east from Bobtail, which is tributary to Deadwood Creek. The conglomerate in this mine is underlain by a sheet of rhyolite which has been intruded between the conglomerate and the schists. As the porphyry dips south the drifts cut through it into the overlying conglomerate, and at the extreme southern end of the mine the latter rests directly upon the Algonkian schists, the porphyry having passed downward into the rocks of this series. The conglomerate, where exposed in the stopes, shows a thickness of from 2 to 6 feet, but only the basal portions have been mined and the actual roof has not generally been reached. The greater part of the conglomerate is unoxidized, the pebbles being imbedded in a matrix consisting largely of pyrite. The porphyry is itself impregnated with pyrite, although no increase in this mineral could be detected near its immediate contact with the overlying ore.

Hawkeye-Pluma.—To the south of the Gentle Annie is the third of the three mines operated upon the Caledonia conglomerate area. Here the hill is capped by a heavy sheet of rhyolite, under which is dolomite, quartzite, loosely bedded sands, and finally about 40 feet of conglomerate, the lower portions of which are gold bearing and rest upon the Algonkian schist. The mine is opened by a shaft and four tunnels. The tunnels run westward from the brow of the hill through the schist into a basin of conglomerate, the gold-bearing portion of which forms a channel trending in a general way north and south, and with an average width of 60 feet. This channel is nearly 1,300 feet long, and strikes about N. 60° E. for about 400 feet in the southern and a few degrees west of north in the northern 900 feet. It lies approximately 200 feet west of the outcrop. On the east side of this channel the schists rise very gradually, so that the three northerly tunnels soon pass from it into the overlying conglomerate, but on the west the rise is extremely steep and the ore is cut off by the sandy beds that form the roof. An incline has been run on this western contact, and farther south a tunnel has been driven for 375 feet into the schists, upraises having been made to the contact above. These relations may be readily made out from Pl. XVIII (p. 214). The ore is nearly 40 feet thick in places, but the average would probably not be more than 6 or 8 feet. In the northern end of the workings the greater part is still in the pyritic condition, the oxidation having been confined to the southern portion of the ore body. When panned both pyritic and oxidized ore show fine scales of waterworn gold. Statements are conflicting as to the value of the material which has been removed, but from the fact that the mine was profitably worked in very early days it is probable that the grade was quite high. A series of assays of the ore now exposed in the workings, made during a systematic sampling of the mine, shows that the high values of from $10 to $12 per ton are confined to the material forming pillars in the center of the stopes, while the marginal conglomerate does not contain sufficient gold to be profitably worked. The mine has now been idle for some years.

MINES IN REFRACTORY SILICEOUS ORES.

As previously described, the refractory siliceous ores occur in five fairly well-defined areas, each of which is separately considered in the following pages. The individual mines are described and no attempt has been made here to give a general geological treatment of these areas, because such will be found in the main body of the text under the heading "Areal distribution" on page 144.

BALD MOUNTAIN AREA.

The Bald Mountain area is the largest and includes the greatest number of mines from which ores of this class are obtained. The ore bodies are taken up and described according to rough groups in which they may for convenience of description be divided. These are shown and named on the map, Pl. IX (p. 214). The individual mines are described from north to south within the limits of each group except where a mine occupies intermediate position.

Buxton mine.—The Buxton mine is situated on the eastern extremity of the divide between Nevada and Fantail gulches, just above the loop in the Fremont, Elkhorn and Missouri Valley Railroad. The workings are upon the basal quartzite and were opened by tunnels on opposite sides of the divide; they are now inaccessible. The ore shoot is very near the surface and is reported to have had a general north-south direction. The mine was an extremely rich one, having produced high-grade ore in considerable quantity.

Retriever mine.—About 800 feet west of the Buxton is the Retriever mine. The ore is in or near the basal Cambrian quartzite, on the same divide between Nevada and Fantail gulches, upon which a long tongue of still uneroded Cambrian lies between the Algonkian measures exposed in the gorges to the north and south. It is opened by two tunnels; one at the north and one at the south end on opposite sides of the divide. Below the quartzite which forms the floor of the ore body is a thick sill of diorite-porphyry. Above the ore is another sill of the same rock. The dolomite intervening between the quartzite and overlying porphyry is up to 5 feet in thickness. One ore shoot only, which follows a fracture that trends slightly west of north, was found in the mine. The fracture or vertical extends upward from the ore into the porphyry, proving that not only the ore, but also the fracture, is of later age than the porphyry.

Stewart mine.—The Stewart mine is located on the divide between Stewart and Nevada gulches and extends through to Stewart Gulch. The country rock is Cambrian shale and dolomite, with underlying basal quartzite. The ore shoot is opened by two tunnels, one at the north and the other at the south end. It is 1,160 feet in length, and strikes slightly east of south, with a width varying between 10 and 60 feet. For the first 680 feet it follows two main parallel north-south fractures. Four hundred and eighty feet south of the north end there is a small ore shoot to the southwest caused by a N. 30° E. fracture which intersects the main vertical. The main shoot here becomes narrow and follows a fracture running north-south, then N. 30° E., and finally it follows a second fracture with a north-south direction. The cross fracture intersects each of the others, and the ore extends only short distances beyond the intersections. The floor of the ore is quartzite; the roof a fine impervious shale. To the east the mine is connected with the Golden Reward by drifts through the barren country rock. The workings are all very close to the surface. The ore from the Stewart is highly oxidized and contains higher values in gold and silver. It exhibits in many cases a peculiar shell-like, subconchoidal parting resembling the exfoliation of weathered granite bowlders. This is a feature which is frequently observed in the highly altered siliceous ores. No sulphide ore has been found in the Stewart mine. The Stewart body is probably a southward continuation of the Buxton, the intervening portion having been removed by the erosion of Nevada Gulch.

Golden Reward mine.—The Golden Reward mine is located on the divide between Fantail and Stewart gulches, just east of the Stewart. It comprises two distinct and disconnected series of workings, one forming the south end and the other the north end.

The northerly workings of the Golden Reward mine and those of the closely adjoining Tony and Maggie claims are upon the same ore shoot and comprise a series of open cuts passing in a southerly direction into stopes a few feet below the surface. The underlying rock is the basal Cambrian quartzite about 25 feet above the Algonkian, but at the southern end of the mine it gives place to porphyry, which gradually rises from the floor until the ore is completely cut off. The roof is shale. At the north end the Golden Reward shoot attained the unusual width of 340 feet, a width greater by 160 feet than that of any ore shoot in the region. This ore body extended south into the Golden Reward mine for 125 feet, and then it divided into three smaller shoots, the two westerly following S. 30° W. fractures, and the others running in a direction slightly east of south. Almost all of the workings are now inaccessible, but the fact that it separates at its southern end into two series of ore-bearing fractures having the usual directions makes it probable that its great size is due to the intersection of numbers of north-south and N. 30° E. fractures. A north-south fault occurs near the eastern side of the Golden Reward ore body and throws the ore down on the east side; the throw is 8 feet, gradually decreasing to nothing at the south end of the mine. There is a space between the two faulted portions of country rock of about 18 inches in width which is filled with fragments of schist and porphyry.

Big Bonanza mine.—This mine is situated on the divide separating Fantail and Stewart gulches between the workings of the Golden Reward on the west and those of the Little Bonanza on the east. The ore outcrops on the north side of the divide, where it is opened by a tunnel. The shoot is very extensive. It occupies almost the entire claim, and is often 15 feet in thickness. It rests on quartzite and comes in contact with a large dike of phonolite on the west side. The workings are now inaccessible. This has been a very productive mine.

Fannie mine.—The Fannie mine is opened by a shaft situated on the southern side of the broad divide between Fantail and Stewart gulches to the northwest of the Little Bonanza, northeast of the Big Bonanza, and about 500 feet east of the long shoots of the South Golden Reward. The shaft is 265 feet deep, and according to F. R. Carpenter affords the following section:

Section in Fannie shaft.

	Feet.
Cambrian shales	70
Cambrian shales, containing a little ore	6
Cambrian shales	4
Trachytoid phonolite	165
Cambrian shales and dolomite	12
Ore	10

The mine is now inaccessible; but from the foreman, Mr. R. Rodda, the following statements have been obtained: There are four bodies of ore. One small shoot trends about N. 12° W., is 10 feet in thickness, and about 30 feet in width. It lies on porphyry. West of this is a broad shoot about 65 feet in maximum width trending likewise about N. 12° W., and dividing into 3 narrow shoots toward the north. This shoot was possibly 40 feet higher than that to the east, but was situated on or near the basal quartzite. Both of these shoots are about 150 feet lower than the workings of the mines to the north and west, but are on the same level with the Sundance shoot to the south, with which the more easterly is probably connected. To the east are two other small and low-grade shoots trending about N. 10° W., and almost north of the large shoot of the Little Bonanza mine. The probable cause of the difference in altitude of the shoots lying in and about the Fannie mine is the intrusion of a sill of trachytoid phonolite from the east. The phonolite has broken irregularly across the Cambrian so that the ore-bearing beds sometimes lie below and sometimes above the eruptive. The ore from the main shoots of the Fannie was of good grade and contained much fluorite.

Little Bonanza mine.—On the north side of the divide between Fantail and Nevada gulches is the Little Bonanza mine. It is separated by a large phonolite dike from the workings of the Big Bonanza mine on the east. On the west side of this dike is a fault that throws the basal Cambrian quartzite down 40 feet on the west side, thus producing a corresponding difference of elevation in the ore-bearing beds of the two mines. The Little Bonanza is opened at the north end by two tunnels. These follow narrow ore shoots, which trend north and south and are separated from each other by a slight fault of possibly 2 feet with the downthrow on the east side. As one follows these shoots southward they unite and the shoot becomes broader until 750 feet south of the opening it is 200 feet wide, although interrupted by a northwardly projecting tongue of unmineralized dolomite that divides it into two portions. From the north end of the mine southward the quartzite assumes an increasingly steep dip to the southeast, which at the widest portion of the ore body amounts to 30°. Together with this dip a series of mineralized fractures with small displacements diverge from the slight fault at the north end, so that in the widest portion of the stope to the south the ore on the east side is 160 feet below that on the west. The amount of displacement along these fractures is generally small, though it sometimes amounts to 6 feet. The difference in elevation of the two sides of the ore body at the south end is brought about by dip and increase in the number of diverging fractures rather than by increase in displacement. The most westerly portion of the shoot continues south at about the same elevation as at the mouth of the tunnel, but divides into three almost parallel shoots. The central shoot is 540 feet long and widens out to about 25 feet, and is in contact with a masss of phonolite on the west side. A large part of the ore mined was of the blue or sulphide variety.

South Golden Reward mine.—The South Golden Reward is opened by four tunnels situated on the south side of the divide between Fantail and Nevada gulches and directly opposite those of the Isadorah on the south. The workings are on quartzite and above the phonolite sill that extends westward from Sugarloaf Mountain. The ore was obtained from two large shoots trending a little west of north, which averaged 600 feet in length by 60 in breadth, but dwindled away at the northern end. Two small shoots lay to the west of these larger ore bodies. The mine is now inaccessible.

Isadorah mine.—The Isadorah is worked through two tunnels that open in the south side of Stewart Gulch just south of the opening of the South Golden Reward. Two small shoots were mined. The easternmost trends north and south and rests on quartzite which lies above the sheet of phonolite that extends eastward from Sugarloaf Mountain; the westernmost trends N. 10° W., and lies upon shales about 4 feet above quartzite. A small auxiliary shoot lies on quartzite a few feet west of the second ore body. It trends N. 20° W., but is very small. The mine has not been very productive.

Sundance mine.—The Sundance mine is worked from a shaft situated in Stewart Gulch about 280 feet west of its junction with Whitetail Creek. It is 265 feet deep and penetrated the same phonolite mass as that cut in the Fannie shaft, probably the western extension of the Sugarloaf mass. The ore is 600 feet east of the shaft and lies on or near basal Cambrian quartzite. It occurs in a single shoot 10 feet thick and of very considerable size, and follows a zone of fracture striking north and south. The shoot had not been explored at the time the mine was visited, but it has since proved to be a very extensive ore body. The strata of the Cambrian are horizontal above and below the ore, but dip slightly away on the east and west sides. The ore was completely oxidized and of very good grade, averaging about $25 per ton and in individual instances containing much higher values. This shoot is probably connected with the more westerly of the two shoots in the Fannie mine.

Billy mine.—This mine is opened by a tunnel located on the west side of Whitetail Creek just north of the mouth of the north fork of the same creek and opposite the openings of the Ruby Bell. It runs west and intersects three small ore shoots that trend north and south to N. 7° W. and follow groups of parallel fractures with the same trend. The ore lies on the basal Cambrian quartzite beneath the heavy sill of trachytoid phonolite that extends northeastward below the workings of the Isadorah and Golden Reward mines. This sill gradually breaks down across the Cambrian until 800 feet west of the mouth of the tunnel it completely cuts off the ore-bearing beds. The Billy has not been a productive mine.

Ruby Bell mine.—The Ruby Bell mine is opened by two tunnels—one in Whitetail Gulch trending southwest, the other in the North Fork of Whitetail trending southeast. There are two shoots of fairly good size, the easterly running a little east of south and probably connecting with the large No. 1 shoot of the Union mine, and the westerly running a little west of south. Between are three small shoots, which are little more than verticals and which extend upward some distance into the shales that form the roof of the usual ore-bearing beds. They are nearly parallel to the eastern shoot. The two more westerly are in contact with a dike of phonolite, one on either side.

In the south end of the most easterly shoot the ore lies beneath an extremely even bed of fine, impervious shale, in which no verticals could be detected. Careful examination of the ore in the breast of the shoot showed that fractures were present in the ore as very slight displacements to the banding of the rock, but that they did not extend upward into the shales that formed the roof. The ore was of the oxidized variety.

Lucille mine.—The workings of the Lucille are slightly to the west of the Isadorah above the phonolite sill above mentioned. The mine was not accessible at the time the region was visited.

Ross-Hannibal mine.—The sill of trachytoid phonolite that extends westward and northward from Sugarloaf Mountain has been cut through by Whitetail Creek draining north, and by the North Fork of the same creek, joining it from the west. In these two creeks are exposed the cliffs formed by the phonolite sill which has cut the ore-bearing beds in two. The shoots of the Union mine lie in the dolomite parting beneath this sill and above the basal quartzite, and the long shoot of the Ross-Hannibal is above the sill. The latter shoot therefore lies almost directly above the No. 3 shoot of the Union, which is separated from it by this phonolite parting. It is opened by tunnels—one on the south bank of the North Fork of Whitetail and the other running westward from Whitetail Gulch. The shoot is 1,500 feet long and is 100 feet wide at the northern end, from which point it trends almost due south and narrows to an extremely slender ore body. South of this narrow portion it widens again and bends east, assuming a direction about S. 27° E. The ore is from 4 to 8 feet thick and lies at all points observable directly beneath a shale roof and upon a floor either of dolomite or phonolite. The capping shale is extremely even and unbroken by verticals except in the narrower portion of the ore body, and even then fractures are very small. Silicified fractures in the No. 3 shoot of the Union below show that the ore was formed after the phonolite intrusion. These fractures have probably supplied the Ross-Hannibal shoot.

Three hundred and forty feet from the south end of the shoot the ore rested on a floor of crystalline dolomite, but was closely in contact with an even roof of blue shales above. This phenomenon is repeated in many mines and seems to show that where an impervious stratum has prevented the upward flow of mineralizing waters the silicification has extended from such impervious beds downward, reaching the floor of unreplaceable rock that underlies the dolomite only along the lines of fracture.

The ore of the Ross-Hannibal was unoxidized sulphide ore. It carried about 80 per cent of silica, and contained much fluorite. A segregation of pyrite at the bottom of the ore body is reported by the owners. Some of the ore contained uranium, and, according to F. C. Smith,[a] 255.08 ounces of silver per ton, with but 0.44 ounce of gold. This was exceptional, however, as the ore was characteristically an ore of gold. The shoot was a rich one and is reported to have yielded an average of $35 per ton in gold.

Union mine.—The Union mine is opened by a shaft situated in the bed of Whitetail Creek about 1,750 feet south of its junction with Stewart Gulch. To the east is Sugarloaf Mountain, to the west is the broad, sloping area that forms the east declivity of Terry Peak, known as Ruby Basin. The shaft passed through the following rocks:

Section of Union shaft.

	Feet.
Phonolite	80
Shale and dolomite	20
Quartzite	7

The phonolite encountered in the shaft is part of a large eruptive mass of laccolithic character which was intruded in the Cambrian series a short distance above the basal quartzite. The workings of the mine have been run in the dolomite that intervenes between phonolite and quartzite.

From the bottom of the shaft a long crosscut extends east and west. In an easterly direction it runs 500 feet, then turns south and follows a S. 50° E. course for 600 feet, connecting with the National shaft. No ore bodies were found on this side of the shaft. To the west it extends 2,260 feet and in this distance four ore bodies are encountered, known as Nos. 1, 2, 3, and 4. The first or No. 1 shoot lies about 100 feet west of the shaft. It is the largest ore shoot of the mine, ranging from 50 to 200 feet in width by about 8 feet in thickness. It was worked at the time of inspection to a length of 1,750 feet. Its trend is nearly due north and south and it is probably connected at its northern end with the Ruby Bell shoot. On the west of the ore body a porphyry dike appears at intervals and another may be seen in the ore south of the shaft cross-

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[a] Trans. Am. Inst. Min. Eng., vol. 27, p. 419.

ing the shoot in a southwesterly direction. The ore in this shoot rested upon or very close to the basal quartzite and beneath a roof of fine, impervious blue shale.

The other three shoots of the mine lie 650, 1,500, and 1,925 feet west of the shaft and all trend in a general north-south direction. They differ from the No. 1 shoot in lying from 4 to 6 feet above the basal quartzite upon a floor of dolomite through which the ore extends downward only along the supplying fractures. The roof is of shale or phonolite. In places the latter rock is extremely irregular, often bulging down into the ore and sometimes passing completely across it and through the quartzite below. A good example of this is given in the sketch (fig. 16), which is a portion of a longitudinal section of the south end of the No. 4 shoot.

A general cross section of the No. 3 shoot is given on Pl. XI, *H* (p. 214). These shoots are also narrower than the No. 1 shoot, but as they are not completely mined out their length has not been determined. The ore of the No. 2 shoot was all sulphide ore. Between the No. 2 and the No. 3 shoots the crosscut intersects a body of phonolite about 500 feet in thickness, which is probably connected with the large phonolite mass encountered in the shaft, or that which forms the Sugarloaf Mountain laccolith. According to those who worked the mine assays of this phonolite were made from time to time and showed values ranging from a few cents to as much as $2 in gold. The rock is extremely fresh and if these values have been introduced at the time of ore deposition they have been accompanied by no visible alteration.

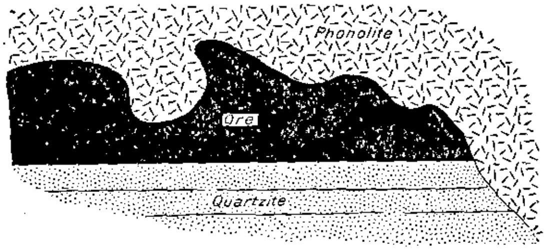


FIG. 16.—Cross section of a portion of No. 4 shoot, Union mine, showing the concentration of ore beneath an irregular phonolite roof.

ALPHA-PLUTUS-MOGUL GROUP.

Clinton mine.—On the south side of Nevada Gulch slightly farther below the opening of the Alpha-Plutus mine are the workings of the Clinton. The tunnel is situated at the bottom of the gulch on the basal Cambrian quartzite, 65 feet below the porphyry sill, which is exposed along the railroad on the south side of the gulch. To the east this intrusive sill breaks down across the Cambrian, so that the workings of the Retriever and Buxton mines to the east are elevated to a horizon above the porphyry to which the name of upper contact has been erroneously applied. One hundred feet from the mouth of this tunnel two narrow ore shoots are exposed, separated by about 25 feet of unmineralized rock. The longest trends due north and south; the other slightly east of north.

The country rock is an extremely decomposed gouge-like alteration of the dolomite or "sand rock." At the south end a cross shoot occurs following a vertical trending N. 22° E., and another very small shoot trending north and south lies a few feet to the east. The shoots dip slightly to the south. This mine has not been a very productive one.

Alpha-Plutus mine.—The workings of the Alpha-Plutus lie beneath Bald Mountain on the north side of Nevada Gulch and extend from the loop in the Fremont, Elkhorn and Missouri Valley Railroad eastward. They constitute the northward extension of the Tornado mine. The mine is opened by a long west crosscut which extends from the north side of Nevada Gulch westward for 1,150 feet. The country rock is the usual dolomitic limestone that lies directly upon the basal Cambrian quartzite but is all in a highly oxidized condition. Nine hundred feet west of the opening is a fault which throws the quartzite up 80 feet on the west; again to the west of this is the continuation of the great Tornado fault that throws the quartzite up about 300 feet on the west side. On the space between these two faults are three long, narrow ore shoots lying at the same elevation as the northern end of the big Tornado shoot. One of these is the continuation of the Tornado shoot and trends N. 20° E., the intervening portion having been cut away by the erosion of Nevada Gulch. This shoot is cut in two by the 80-foot fault, which seems to be post-mineral. West of this about 100 feet is a shorter parallel shoot from the north end of which a shoot trends S. 12° E. intersecting the first-named ore body. On the east or downthrown side of the 80-foot fault are sixteen narrow shoots varying from 50 to 600 feet in length and trending N. 20° W.; N. 15° W.; N. 60° W.; N. S.; N. 25° E., and one small shoot N. 45° W. A few small dikes of grorudite striking N. 7° W. were cut in the northern portion of the mine. These shoots are widely spaced and uniformly narrow, few of them exceeding 5 feet in width, and are often very high, sometimes being stoped up for 15 feet. The fractures were open and manifold and no displacements could be observed at intersections. All of the shoots dwindled to mere verticals in a northerly direction.

This mine has produced considerable ore, but most of it of slightly lower grade than that on the south side of Nevada Gulch. This is the only mine on the north side of Nevada Gulch in which any appreciable amount of ore has been found.

Tornado mine.—The Tornado mine is worked through a shaft 315 feet in depth, situated 720 feet west of the railroad trestle in Fantail Gulch. There are 36 distinct shoots of ore in the mine, which lie upon or close to the basal quartzite of the Cambrian and about 25 feet above the Algonkian. A very good idea of the relative position and size of these ore shoots can be obtained from the map, Pl. IX (p. 214). Two of them were of exceptional size, and have furnished the larger portion of the output of the mine. The main, or "Big," shoot, as it is termed by the owners, is the largest single body of refractory siliceous ore yet mined. From its outcrops in Nevada Gulch beneath the railroad trestle it extends in a direction slightly east of south for a distance of 1,225 feet. It then turns to a direction S. 15° E., which it follows for the balance of its course. At the north end it is about 10 feet in width, but widens as it is followed inward until at a point 210 feet directly west of the Tornado shaft it attains a maximum width of 180 feet. From this point south it narrows to about 10 feet and again widens at the southern end, where it passes into the property of the Horseshoe Company. The thickness of the ore between quartzite and overlying shales is about 6 feet, but increases at some points to upward of 14 feet. The roof of the ore is shale for the greater part of the length, but at several points this is replaced by a sheet of igneous rock. The floor upon which the ore rests is in most cases quartzite, which at several points gives place to a projecting sill of trachytoid phonolite, connected with a dike on the west. In the south end of the mine the Algonkian projects up into the ore, and is itself reported to have carried refractory values which in some cases reached $12 per ton. Seven hundred and fifty feet south of its outcrop in Nevada Gulch, the Big shoot is thrown down 72 feet on the south by a fault, striking N. 22° E. For some distance north of this fault, and through the northern end of the downthrown portion to the south, the continuity of the ore is broken by many north-south porphyry dikes of varying thickness. From a point directly west of the shaft the ore comes closely in contact with a large 60-foot dike of trachytoid phonolite on the west side. This dike extends far south into the workings of the Mogul mine, where it finally dwindles to nothing. The direction of the ore body from the point where it joins the dike is S. 12° E. for the rest of its course. Many small shoots of ore, with varying strikes, join this large body on the east side, and the grade of the ore is increased at such junctions. The ore is partially sulphide and partially oxidized, and carries average values of about $17 per ton. It is higher in the vicinity of the dikes and faults at the northern end, but becomes considerably lower at the point where the shoot attains its greatest width.

The other large shoot of this mine is that known as the Bottleson shoot. It extends from a point 600 feet north of Nevada Gulch for a distance of 1,500 feet to the Bottleson shaft and is there deflected to the west. Three hundred feet south of this shaft it terminates in an ore shoot 30 feet in width, trending S. 47° E., which occurs along a fault fissure that throws the southwest side down 8 feet. At the southeast end of this cross shoot are two other ore bodies, one small and extending 700 feet to the northeast; the other large and irregular and extending 1,100 feet to the southwest, with a strike of N. 25° to 30° E., finally uniting with the long narrow ore body known as the "E" shoot. This has been considered on the map as a part of the Bottleson shoot, although really a separate ore body. The width of the Bottleson shoot varies from 25 to 65 feet. The roof is shale, and the floor at times quartzite and at times dolomite. Many interesting fractures occur in the roof, following the longer diameter of the ore body. Twelve of the other smaller shoots of the mine are parallel to the southern end of the Big shoot, and trend between N. 12° and N. 15° W.; thirteen trend between N. 15° E. and N. 30° E.; one trends N. 47° W.

One hundred feet east of the Tornado shaft is an ore body 700 feet in length, known as the "A" shoot, following a manifold fracture with a N. 20° E. trend. Between this shoot and the Bottleson shoot, a distance of 500 feet in an easterly direction, is a long crosscut, which runs upon the basal quartzite and intersects no ore-bearing fractures. This barren region forms a syncline in which the quartzite and overlying limestone dip away from the ore bodies in either direction at angles of 20° and 15°, respectively.

At the south end of the mine, and about 350 feet east of the phonolite dike, is a comparatively narrow ore body 950 feet in length, known as the "E" shoot. The ore in this shoot was of good grade, often averaging as much as $35 per ton. It followed a strong vertical, which shows little or no displacement. The ore—like much of the ore in this part of the mine—does not rest on the quartzite, but lies at a distance of perhaps 4 or 5 feet above it at the north end of the shoot. This interval increases to 12 feet where the shoot passes into the Mogul ground. The floor consists of dolomite.

Besides these four shoots described, there are on the east of the large phonolite dike previously mentioned twenty-eight other ore bodies that have added materially to the production of the mine. While not separately considered here, a very good general idea of their relative size and importance may be obtained from the map (Pl. IX, p. 214).

On the west side of the large dike which forms the west wall of the large or main ore shoot the conditions are somewhat different from those to the east. At a varying distance west of the porphyry the crosscuts which penetrate this dike encounter a displacement which throws the west side up for a distance of nearly 300 feet. In Nevada Gulch this fault is reported to have been very near the west side of the phonolite dike, but at a point northwest of the Tornado shaft it diverges from the dike, which is deflected to the east, so that on the boundary between the Golden Reward and Horseshoe properties the two are separated by an interval of 700 feet. This fault continues into the Horseshoe property and appears just west of the Troy shaft, where it shows a clear offset of 300 feet. At the point of divergence it is joined by a 72-foot fault that cuts the large ore shoot into two portions with a downthrow of 72 feet on the east. Directly on the west side of the large phonolite dike there is another displacement by which the west side is thrown down for 40 feet at the south end of the mine. The amount of displacement decreases to the north, however, until due west of the Tornado shaft it is practically zero. This displacement, unlike the others in the mine, seems to have occurred at the time of the porphyry intrusion, as it is accompanied by no brecciation or slickensides. The porphyrys and sedimentaries show a close and typical intrusive contact, often exhibiting considerable metamorphism.

Directly west of the shaft there are between these two main faults a series of small displacements which form narrow benches as one passes westward from the phonolite dike. By two of these the quartzite is elevated on the west side successively 30 and 40 feet; others are much smaller. The actual offset in these displacements is extremely small, and much of the difference in elevation is absorbed in an extremely steep easterly dip.

On the separate benches between these displacements are six small ore bodies which trend about N. 3° to 5° E. Considerable ore of good grade was found in these shoots, which are of smaller size than those generally encountered in the mine. Pl. XIX (p. 214) gives an east-west cross section of the mine and will bring out these relations clearly.

The ore from the Tornado mine was partly red or oxidized and partly blue or sulphide ore. In the early history of the mine the oxidized ore was especially sought on account of the additional difficulty of treating the unaltered sulphides, but with the more complete understanding of smelting this preference came to be disregarded.

The ore from the Big shoot is very markedly banded on account of the persistence of beds of shale in a comparatively unaltered condition. In some of these the shale bands contain soft white clay, which has presumably resulted from the decay of thin seams of porphyry. This clay not infrequently contains high values in gold. A partial analysis of it gave the following results:

Analysis of clay from Big shoot of Tornado mine.

SiO_2	36.8
FeO	.19
Al_2O_3	16.5
H_2O (combined)	15.3
Ounces of gold	2.47 ($49.40)
Ounces of silver	.9

It is stated that in some cases this clay carries values as high as $200 or $300 per ton in gold.

In general, the ore from this mine averages about $17 per ton in gold. In the northern end of the Big shoot, where many faults and a large number of dikes interrupt the continuity of the ore, the contained values are higher, often averaging $35 per ton; in the large flat body directly west of the Tornado shaft they are comparatively low, much of the ore mined carrying only $10 per ton. The ore here is little broken or disturbed. The grade is higher where the large ore body is joined by lateral shoots. Little or no secondary enrichment has taken place in the mine, for there is little relative difference between the values yielded by altered and unaltered ore.

Great Mogul mine.—The Great Mogul mine is opened by a shaft 305 feet in depth, situated in Stewart Gulch, at an elevation 5,986 feet above sea level and about 1,600 feet west of the loop of the Fremont, Elkhorn and Missouri Valley Railroad. The shaft penetrated two sills of porphyry, separated by about 15 feet of Cambrian shales, the upper being relatively the thicker. Between the lower sill and the basal Cambrian quartzite occurred interbedded shales and dolomite, the more completely marbleized layers of which rested on the quartzite. The Cambrian rocks dip east at an angle from 12° to 15°. The mine comprises two large ore bodies. The first was encountered 250 feet directly west of the shaft, and by reason of the strong eastward dip is worked by a horizontal drift that connects with the shaft 30 feet above quartzite. It is the southward continuation of the large shoot of the Tornado mine. It is 110 feet in maximum width and about 5 to 10 feet in thickness. At the north end it is divided into two portions by a long neck of unmineralized rock. Toward the south it gradually narrows, until about 1,350 feet south of its connection with the Tornado it dwindles out. On the west side is a dike of trachytoid phonolite sloping slightly east and benching out beneath the ore. From its contact with this dike on the west the ore dips eastward at an angle which increases slightly in an easterly direction away from the dike. This dike, like the ore shoot, pinches out to the south. The major fractures in the shoot trend north and south, but often there is so intricate a network of minute verticals in the shale roof that it is impossible to distinguish any predominant direction. West of this dike is a fault which throws the west side down for 40 feet at the north end and increases in amount as we proceed south, until at the end of the dike the displacement amounts to 100 feet. On the downthrown side of this fault is the second large ore shoot of the mine. This shoot is 75 feet in maximum width at the north end and lies against the phonolite dike on the east side. Farther south it leaves the contact with the phonolite and narrows until finally it dwindles to a mere vertical. On the west side of the ore is a ledge of Algonkian quartzite, and beneath the ore for the larger part of its southerly course is a floor of the same rock. The basal Cambrian quartzite, which became very thin below the ore in the upper shoot, is here entirely absent. This shoot is connected with the shaft by a drift which passes beneath the main shoot through the Algonkian. Iron-stained fractures may be seen beneath the easterly shoot parallel to the lamination of the schists. These may be the downward continuations of the mineralized fractures or verticals in the stope above. A cross section of this mine in an east-west direction is given in Pl. XX (p. 214). The ore from the Mogul is partially oxidized in some places and completely so in others. At several points, presumably in the lower shoot, the ore contained great numbers of angular fragments of Algonkian rock, among which were scattered crystals and isolated masses of jarosite. In the upper or eastern shoot layers of very rich clay were found interbedded with the ore. These often carried several hundred dollars per ton in gold. The Mogul has been a very productive mine.

Little Tornado mine.—To the west of the 300-foot fault on the divide between Nevada and Fantail gulches are the dismantled workings of the Little Tornado mine. They are presumably upon the basal Cambrian quartzite, as that stratum is exposed at the same elevation in the Double Standard tunnel, a short distance to the southwest.

There are two small shoots striking N. 10° E., following strong, rather open fractures, which converge toward the north and together extend through to Nevada Gulch. These shoots are separated by a slight fault which throws the eastern shoot down 10 feet, while from the south end of the latter a third small ore body trends N. 34° E., to be intersected midway of its course by four very small ore bodies parallel to the first two. The strata have a pronounced easterly dip, which, together with many slight displacements having downthrows on the east side, marks the approach to the great 300-foot fault (mentioned on page 127). Two small dikes of rock related to grorudite and striking N. 80° E. cut directly across the ore shoots of this mine. Country rock and ore were alike extremely oxidized. The mine has not been a heavy producer.

Double Standard mine.—In the head of Fantail Gulch, above the town of Terry, on the north side of the gulch, is the tunnel of the Double Standard mine. The tunnel is driven upon the basal Cambrian quartzite, trends slightly north of west and intersects seven long, narrow shoots of ore at 100, 150, 200, 287, 312, 412, and 500 feet west of the opening, respectively.

The first two are small and strike N. 10° E. and N. 22° E. with a large dike of coarse-grained rhyolite between. The third or main Double Standard shoot trends N. 4° E. and extends north 900 feet, where it outcrops high up on the south side of Nevada Gulch. The ore lay in close contact with a dike of rhyolite on the east side for 300 feet and then a slight fault has brought the

Algonkian schists into contact with the ore. The other shoots are short and narrow and trend N. 25° E., N. 30° E., and N. 7° E. All follow strong and rather open fractures, which are mainly vertical in position. Two of these shoots converged toward the south, and at the point of intersection formed a large body of ore 5 feet thick with an extremely even shale roof. Where the fractures come together they have slightly discordant dips and intersect one another in both horizontal and vertical planes, but no displacements could be detected at the intersection. There is a prevailing southwest dip in the mine and slight undulations interrupt its regularity, the shoots always lying on the crests of the anticlines. The shape of the ore bodies in cross section throughout this mine varied considerably, some being elliptical and others so irregular that the ore extended out in thin shelf-like masses into the country rock. A shoot was observed in which a shelf-like mass of this character, about 1 foot in thickness, lay immediately beneath the shales that overlay the ore and extended from 3 to 6 feet beyond the main body of the shoot. Much of the ore from this mine was unoxidized, and that from the shoots to the south of the crosscut carried large quantities of gypsum and green fluorite.

Boscobel mine.—At the extreme west end of the Double Standard crosscut tunnel a 10-foot fault has thrown the basal quartzite up on the west. On the upper side of this fault is the long shoot of the Boscobel, which extends south 400 feet, where it dwindles to a mere vertical, and north for 1,050 feet to its outcrop in Nevada Gulch. Midway along its northerly course there is a small vertical ore shoot, a few feet to the west, striking N. 35° E. West of the main shoot, where it outcrops in Nevada Gulch, three small shoots are situated. The two most westerly are at a high angle to one another, so that they converge to the south, and together form an ore body parallel to the main Boscobel shoot. The most easterly of the three is between the latter and the converging shoots. The fractures of the Boscobel mine are prominent and often inclined at a slight angle to the east. Dikes of rhyolite lie in contact with the ore of the main shoot on both sides and in many cases divide the ore into two portions.

Throughout the entire country between the Boscobel and Double Standard shoots, and thence eastward as far as the mouth of the Double Standard crosscut, great numbers of north-south dikes of rhyolite occur. The ore sometimes lies in contact with them and at others diverges from them at considerable angles, showing that the occurrence of the ore is independent of this igneous activity, so far at least as the direction of ore shoots is concerned.

The ore from the Boscobel shows great quantities of brilliant green fluorite, together with extremely large crystals of barite, the latter embedded tightly in the ore.

Hardscrabble mine.—In the end of Fantail Gulch, just below the sharp southward bend in the stream, is a long open cut from the west end of which a tunnel leads westward into the Hardscrabble mine and thence through to the Welcome shaft. South of this open cut, and south also from the tunnel, is a series of irregular stopes, open to the north, from which low-grade ore was mined. These bodies passed into fairly regular stopes toward the south, but in the neighborhood of the open cut the ore was included between an inextricable tangle of dikes, sills, and irregularly bounded masses of rhyolite. The workings are presumably near the basal quartzite of the Cambrian, for that rock is exposed in the Welcome mine to the west. Fractures pass through rhyolite, shales, and dolomite indiscriminately. To the north of the tunnel and open cut are a series of narrow shoots following fractures that trend N. 20° E., and probably connect with the shoots of the Double Standard. Southwest of the Hardscrabble workings is a long shoot trending northeasterly, and connecting with the workings of the Welcome mine. It is inclined sharply south, following the dip of the quartzite, and on the east is in contact with a dike of rhyolite. The ore from the Hardscrabble mine contained great quantities of purple fluorite, and some of the rhyolite itself was so heavily impregnated with this mineral that it contained workable values.

Welcome mine.—The Welcome mine is opened by a shaft situated on the northwest side of Fantail Gulch, just above its bend toward the south. It is sunk on a fault which strikes north and south and throws the west side down 30 feet, but dies away to the south. The strata dip to the south at an angle of from 10° to 12°. About 25 feet west of the shaft is a shoot 100 feet wide by 10 feet in thickness and 625 feet in total length. This large ore body is caused by the occurrence of innumerable parallel fractures which, while they are strong and display considerable opening, are so closely spaced that they have produced an ore body of great size. (See Pl. XIII, p. 214.) So close are they to one another that the shale roof has been sufficiently silicified between to carry considerable values. This shoot terminates against an eastward-dipping dike or crosscutting sill on the west side and gradually dwindles to a mere vertical on the south. West of the south end of this large shoot are a great number of small shoots on fractures striking north and south, N. 10° W., N. 15° E., and N. 30° E. Much of the ore in this mine was separated from the quartzite by from 2 to 3 feet of red dolomite. The Welcome has been a heavy producer.

Harmony mine.—This mine is opened by two tunnels on the south side of Fantail Gulch above the town of Terry. The workings are now inaccessible, but from the map there seems to be a series of small shoots trending N. 5° to 10° E. The workings are directly south of the Little Tornado and just west of the great 300-foot fault.

Ben Hur mine.—On the south side of Nevada Gulch, some distance north of the opening of Cherry Creek is the tunnel of the Ben Hur mine. It runs a little south of west down a gentle incline through the schists of the Algonkian. It then encounters a dike striking parallel to the schists. On the west side of this dike a fault has thrown the Cambrian down so that the quartzite is on a level with the adit and the porphyry dike has turned over into a sill toward the west, so that about 5 to 6 feet of Cambrian-banded dolomite and shales intervene between quartzite and eruptive rock. Lying directly against this eruptive rock on the east and beneath the sill is a large shoot of ore. South of the tunnel the ore body turns sharply southwest, presumably following a coordinate fracture and then sharply south, so as to resume its original direction which it maintains for a considerable distance.

The fracture which supplied the ore passed up into the porphyry and was about 3 inches in width and filled with a mass of large interlocking quartz crystals, which projected from a narrow band of silica into the open space between the walls. This quartz-crystal ore was reported to have yielded high values. In the extreme south end of the mine the ore lies against the Algonkian schists, probably on account of slight faulting. The ore from the Ben Hur was oxidized and carried high values, sometimes yielding $60 per ton in gold. The mine is still productive.

Baltimore mine.—The Baltimore shaft is situated in the bed of Nevada Gulch south of the saddle between Bald and Green mountains. The country rock is an eruptive, probably related to the grorudites. This is intersected in the shaft to a thickness of 60 feet; below is a parting of Cambrian shale 40 feet thick, another sill of eruptive rock 20 feet thick, and then 110 feet of Cambrian shale and dolomite. The shoots are scarcely more than verticals and lie in the dolomite above the basal Cambrian quartzite. Two trend N. 20° E., two N. 25° W., and one N. 70° E. These verticals have not been indicated on the map in Pl. IX (p. 214) on account of the uncertainty as to their exact location.

MINES ON THE UPPER ORE-BEARING BEDS.

Daisy mine.—The workings of the Daisy mine are situated on the divide between Fantail and Stewart gulches just east of the 300-foot fault and directly over the most westerly shoots of the Tornado. They are but a few feet below the surface. The country rock is a green glauconitic shale, containing bands of dolomite, but exhibiting no heavy beds of the latter type. The ore is colored green by much included glauconite and contains many large cavities or vugs distributed without regularity.

Upper Welcome mine.—West of the Welcome shaft and far up on the northwest slope of Fantail Gulch are some small workings that are at a much higher altitude than the workings of the Welcome mine. The country rock is Cambrian shale containing great quantities of glauconite and intercalated layers of a dolomitic character, none of which are very thick. The ore was mostly in the nature of narrow silicified shoots following small north-south fractures, but extending only short distances laterally from them. Much eruptive rock occurs in rather confused relations. The geological position is probably about the same as that of the Daisy mine and may correspond to the upper contact of the Portland district. This and the Daisy mine to the east are the only ore bodies in the Ruby Basin district that are in what may be properly termed upper ore-bearing beds. The fact that the country rock is such an impure variety of dolomite, interrupted by many shale bands, indicates that ore-bearing beds which exhibit considerable uniformity of texture and freedom from impurities at one locality may give place to comparatively unreplaceable rocks at another.

PORTLAND DISTRICT.

Dividend mine.—The Dividend mine is situated upon the northern slope of Green Mountain, a little north of east from the town of Portland. It is operated by two tunnels running into the hillside and opening into a small tributary of the north fork of Deadwood Gulch. The workings are about 20 feet above the Algonkian upon the basal Cambrian quartzite, which dips slightly west of south at an angle at from 4° to 6°. Two small flat bodies of ore were mined from the northeast end of the mine. They occurred at the intersection of many small fractures which trended N. 25° E., N. 44° E., and N. 18° W. The ore rests on quartzite and beneath a thin bed of shale, but ends abruptly on the west against soft Algonkian phyllites, which are faulted up by a slight displacement trending about N. 78° W. The ore in these two bodies was irregularly bounded and about 5 or 6 feet in thickness. Mineralized fractures pass from the ore into the Algonkian, in which rock they have yielded some pay ore. Another small ore body occurs in the extreme southwest end of the mine at the intersection of fractures trending N. 30° E., N. 38° E., and N. 36° W. This ore body is about 500 feet northeast from the nearest mine, in the upper ore-bearing beds, and is separated from them by an interval of Cambrian strata and intruded porphyries 527 feet in thickness. The other ore bodies of the mine were narrow shoots, seldom more than 5 feet in width, which followed rather open fractures but often extended to considerable distances in a vertical direction, in one case as much as 40 feet from the quartzite. The largest of these fractures contained fragments of Algonkian schist, and was sometimes 6 inches in width. It trended N. 53° E., and carried ore for 740 feet. Other small ore shoots followed fractures trending north and south, N. 15° E., N. 25° E., N. 44°–53° E., and N. 34°–40° W. The fractures are open and but little mineralized when compared with those occurring on upper contact and in mines where the ore bodies are extensive flat masses. Dikes of decomposed eruptive rock of a few feet in thickness occur in great numbers; many of these have breccias along their contacts. The dikes appear to intersect the verticals, but the rocks are too decomposed to give positive evidence.

The ore is of three varieties: The first is a gouge-like decomposed material heavily charged with oxides of iron and manganese, and often containing considerable sandy fluorite; the second is a sandy material resulting from the disintegration of the basal quartzite and often mined to its contact with the underlying schists; the third is the usual hard refractory siliceous ore. The first two varieties of ore carried values of from $10 to $25 per ton, but the siliceous ore generally contained from $25 to $50 in gold with but little silver, which is strongly in contrast with ore of the same character in the upper beds, the latter yielding uniformly low values and a relatively high silver content.

A peculiar, hard, ferruginous jasper occurs in this mine in the same banded masses as the ore, but it carries no workable values. It is termed "liver-colored rock" by the miners.

Snowstorm mine.—The Snowstorm shaft is located in the extreme head of Nevada Gulch. It is about 345 feet deep and has produced no ore. It is important in that it comprises an extensive series of barren workings on the basal Cambrian quartzite and indicates that ore bodies are probably absent in the barren region lying east of the Portland district.

Two Johns mine.—The Two Johns mine is located in a southwest tributary of main Squaw Creek, about 1 mile east of north from Crown Hill. The basal quartzite and about 20 feet of the Cambrian rocks are here exposed and outcrop all along the west bank of Squaw Creek, dipping southwestward from the great porphyry mass that forms War Eagle Hill. Above the shales is a thick sill of rhyolite. The mine is opened by two tunnels on the basal quartzite which diverge at the mouth, one running southeast and the other southwest. There are two long, narrow shoots of ore, the southern trending N. 50° E., and the northern composed of two portions, of which the eastern trends N. 70° E. and the western N. 25° E. At the junction of the two portions the ore body is 20 feet wide, the ore of the small shoots following fractures that strike between N. 70° and 50° E. Two small dikes of eruptive rock cross one of these ore bodies and the fractures do not pass through them. On the west side all of the shoots are cut off against an eastward-sloping wall of dark, coarse-grained rhyolite. The mine has not been a very productive one.

Gushurst and Manchester.—On the quartzite rim that is exposed in the head and on the west side of Squaw Creek are a few small workings that belong to the Gushurst and Manchester mine. There occurred in these workings in the dolomitic shale a few isolated masses of jasperoid rock in which irregular patches of galena and cerussite were found. These mines have not produced much ore.

Labrador mine.—In Labrador Gulch at an elevation of about 5,500 feet above sea level is an exposure of Cambrian rocks much distorted by intrusive sills and dikes. There are a few workings that have yielded some refractory siliceous ore. These are now inaccessible.

Decorah mine.—The workings of the Decorah mine lie on the eastern side of Green Mountain. They are opened at the north end by two tunnels about 50 feet above the railroad and follow two long narrow ore bodies southward for a distance of 650 feet. The workings are about 20 feet below the *Scolithus* sandstone which lies at the top of the Cambrian series. The country rock dips slightly to the south-southwest, and the ore bodies trend S. 35° W., following the dip. The easterly shoot is from 25 to 30 feet wide at the south end, but gradually narrows to a mere vertical at the north. A little south of midway along its course it widens to the west until it has attained a maximum width of 100 feet. Shales form the roof of the ore body and the floor upon which the ore rests. The fractures are extremely strong and open, sometimes occupying the entire roof of the stope. The ore is from 2½ to 3½ feet thick and corresponds exactly to the thickness of the replaced bed of dolomite. The more westerly shoot is narrower and at the south end the ore extends up into the shales that form the roof, thus forming a very narrow vertical ore body.

Trojan mine.—The Trojan is opened by a tunnel running S. 35° E., and situated on the north side of Green Mountain east of the workings of the Decorah. The country rock is here Cambrian shales, very glauconitic, with an interbedded layer of dolomite about 4 to 5 feet in thickness. The mine comprises a broad, flat stope about 700 feet long and 85 feet in maximum width, but narrowing toward the southern end. At the south end the ore is divided by a dike of coarse rhyolite striking N. 35° E., which is itself greatly silicified in places, and often stained dark brown where it comes in contact with the ore. The ore from the Trojan yielded relatively high values in silver, thus contrasting strongly with the ore taken from the Dividend mine to the north and lying upon the basal Cambrian quartzite 527 feet below.

Alameda.—The Alameda is an open cut at the south side of Green Mountain and is probably a continuation of the Decorah. Fractures run about S. 35° W. and the country rock dips about 8° in a direction S. 8° W. There is a bed of considerably oxidized fine-grained dolomite 2 feet in thickness, above which are 14 feet of glauconitic shales with thin interbedded layers of a dolomitic character. The vertical seen in this open cut shows a heavy bed of ore replacing the main dolomite layer, but upon passing into the shales above the silicification is confined to a slight replacement of the thin dolomitic layers. The ore from the Alameda is of low grade, not generally averaging more than $9 to $10 per ton.

Folger mine.—The Folger mine is on the south side of Green Mountain about 150 feet west of the Alameda. The ore shoot is small and trends N. 30° E. but divides into two portions at the northern end. A few fractures are present but the roof as a whole is an extremely uniform and unbroken bed of shales.

Perseverance mine.—The Perseverance mine is opened by a tunnel situated about 200 feet west of the Folger and running N. 35° E. from the south side of Green Mountain. There are three ore shoots, the central one of which is very narrow. It widens at the north end into a broad, flat stope about 50 feet in width in which few, if any, verticals can be observed in the shale that forms the roof. The other ore shoots trend in the same general direction and the ore is about 3 feet in thickness. It lies between two beds of shale. In the more westerly shoot there are two blankets of ore, one above the other, separated by an interval of unmineralized shale.

Empire State mine.—The Empire State mine is opened by a long tunnel extending southward from the north side of Green Mountain completely through the hill and connecting with the workings of the Mark Twain on the southwest. The ore is from 2½ to 3 feet in thickness and lies between two beds of impervious shales. In places it comes in contact with irregular beds of coarse-grained rhyolite. Fractures trend N. 25° E. and N. 35° E. Many of the shoots occurring in this mine are very broad and flat, the roof being interrupted by few fractures. The average thickness of the ore is from 2½ to 3 feet.

Mark Twain mine.—The Mark Twain mine is opened by a series of tunnels running from the head of Nevada Gulch in a northwesterly direction. The country rock is a Cambrian shale with two interbedded layers of dolomite separated by about 5 feet of shale. The lower layer of dolomite is 3 feet in thickness; the upper is 2 to 2½ feet. The ore forms a large, irregular channel-like mass 1,200 feet in length. It lies in two blankets of extremely even upper and lower contacts and replaces two beds of dolomite. Much glauconite occurs in the shales. Fractures are present in this mine intersecting one another in an irregular manner. The most frequent of these trend N. 35 to 40° E. Many others occur striking N. 85° E., N. 60° E., N. 50° E., N. 80° W., N. 33° E., and N. 10° W. The irregular character of the Mark Twain stopes is due to the intersection of these fractures. At the south end of the mine the strata of the Cambrian bend upward sharply toward the southwest. The ore is largely sulphide ore, and the values which it contains are often distributed with great regularity. The Mark Twain has been a very productive mine.

Leopard and Jessie Lee mine.—This mine is entered by a tunnel on the north side of Green Mountain, a few feet east of the town of Portland. The workings lie about 20 to 25 feet below the *Scolithus* sandstone which is exposed in the cut of the Burlington and Missouri River Railroad near the railroad station. The ore occurs in large irregular flat masses, about 40 feet in maximum width and about 2 feet in thickness. It lies apparently upon a 3-foot sill of coarse-grained rhyolite and beneath argillaceous and glauconitic shales. The fractures in the roof are extremely small and follow directions N. 20° E., north and south, and N. 20° W.

Burlington and Golden Sands mines.—The Burlington and Golden Sands mines are opened by a tunnel that enters the north side of the hill just above the railroad. A few feet from the mouth of this tunnel is a long crosscut that runs southeast and connects with the workings of the Leopard and Jessie mines. In the shoot there is intersected a series of broad shoots of ore trending as a whole about N. 35° E., and lying about 18 feet below the *Scolithus* sandstone that forms the uppermost layer of the Cambrian series. The ore-bearing beds are about 2½ to 3 feet thick, but are interrupted by more than the usual number of shaly layers. They are overlain and underlain by glauconitic shale. There is a slight southwesterly dip throughout the mine. The fractures are widely spaced but extremely strong, for the silicification has often extended for 6 inches from them in the shales that overlie the ore-bearing beds. The shoots follow fractures which trend about N. 35° E., and are intersected by others running N. 13° E. and occasionally N. 60° E., the largest bodies of ore occurring in the vicinity of such intersections. The ore is about 2½ to 3 feet thick. At the southeast end of the mine another blanket of ore was discovered about 6 feet above the first and separated from it by glauconitic argillaceous shales.

Portland mine.—The Portland mine is situated west of the town of Portland just south of the crossing of the narrow and wide gage railroads. There are two dolomite beds that carry ore, all dipping slightly southwest and interbedded with argillaceous and glauconitic shales. At one point there is a small bed of dolomite 8 inches thick intervening between the other two. These beds are not continuous over any very extended area, for they often become shaly or grade into comparatively unreplaceable rock. The more easterly portion of the workings is about 20 feet higher than that to the west, and comprises an open cut and three vertical very narrow and high ore bodies, all in the shales that overlie the principal ore-bearing beds. The ore from these workings contains very high values in silver, but, as is usual with ore bodies in the comparatively impure dolomitic shales, extends but short distances from the supplying fractures. There are three large verticles of this type trending N. 25° E. and a smaller one

N. 40° E. In the western workings which are opened by a long southeast crosscut are several small shoots containing blankets of ore, generally not more than 2 feet in thickness and following strong fractures which trend N. 20° E., N. 25° E., N. 30° E., N. 40° E., N. 55° E., N. 80° E., and N. 35° W. Intersections are generally without appreciable displacement. The N. 25° to 30° E. fractures are the stronger and the most of the ore bodies trend in that direction. The *Scolithus* sandstone lies about 25 feet above the lowermost blanket of ore. The most westerly stope of this mine is a small shoot 20 feet high but of small horizontal dimensions. It yielded very high values in silver. A considerable amount of ore has been mined from the Portland.

Clinton mine.—The Clinton mine is located about 1,500 feet west of the town of Portland and is worked through a tunnel connecting with the Portland mine to the northeast. The country rock is the glauconitic shale of the Cambrian and inter-bedded layers of dolomite that lie about 20 feet below the *Scolithus* sandstone and constitute the so-called "upper contact."

There are three large shoots in the mine. The more easterly shoot is 6 to 8 feet wide, trends N. 44° E., and is about 300 feet long. The ore is 3 feet thick. The major fractures trend N. 25° E., N. 32° E., N. 44° E., and N. 50° E.; minor fractures run north and south, N. 86° E., N. 85° W., and N. 58° W. The large shoot is formed by the intersection of major fractures running N. 32° to 44° E., and minor fractures running N. 50° to 85° W. This large shoot divides at the north end into two portions. The other shoot is 30 feet northwest and trends N. 32° E., following parallel fractures with the same trend. Forty feet east of the long narrow shoot is a shoot trending N. 53° E., and crossing at a small angle a series of parallel fractures striking N. 32° E. The Clinton has been quite a productive mine.

Gunnison mine.—The Gunnison is a small but comparatively unproductive mine about 400 feet west of the Portland and south of the railroad. The tunnel is upon a horizon somewhat lower than that of the majority of mines in the region. The ore is low grade and occurs in several blankets, replacing beds of dolomite and separated by varying intervals of glauconitic shales. The mine has produced but little ore.

South Dakota mine.—This mine is on the northeast side of Annie Creek on a spur that juts out from Foley Mountain. It has yielded but little ore and that of low grade. As many as six small blankets of ore are reported to have occurred in the mine.

LEAD AREA.

Sula mine.—The Sula mine comprises an open cut north of the junction of Poorman Gulch and Gold Run excavated directly upon the basal measures of the Cambrian. The ore is of two varieties, one containing much barite and carrying refractory values in gold ranging sometimes as high as $25 per ton, the other carrying irregular patches of granular wolframite. The mine has not been very productive.

Harrison mine.—The Harrison mine is situated on the top of the hill just north of Lead. It is opened by a tunnel that trends northward and the ore lies but a few feet below the surface. The strata dip quite sharply toward the east. There are three varieties of ore in the mine—refractory siliceous ore, tungsten ore, and auriferous conglomerate.

The refractory siliceous ore lies in the dolomite directly on the basal Cambrian conglomerate and beneath a roof of shales. It forms a blanket about 3 feet in thickness. It is a whitish granular-looking rock, often mistaken for mineralized quartzite, and carries great quantities of barite in crystals and irregular masses. The average yield of this ore is $60 per ton in gold.

The second variety of ore is a granular wolframite which appears as a rim around the refractory ore and generally forms a capping of variable thickness to the latter. It also appears as irregular patches throughout the siliceous ore. This wolframite contains many cavities in which crystals of wolframite together with white and green scheelite occur in considerable abundance. Fine radiating aggregates and a few distinct crystals of barite are scattered through it, and a drusy coating of gold-yellow ferric sulphate, which is often mistaken for tungstite, covers the more oxidized specimens.

The third variety of ore is the auriferous conglomerate, which has a thickness of 15 feet and lies below the refractory ore in a depression upon the Algonkian surface. This conglomerate was all highly oxidized and consisted of water-worn pebbles of quartz and Algonkian quartzite with a few fragments of schist embedded in a matrix composed of finely divided detrital quartz and iron oxides. Some free gold occurs in the conglomerate, which is richest in the basal portions. The depression in which this occurs is 78 feet wide and trends northwest. It is reported to have been bounded by slight elevations in the Algonkian surface.

This mine has been productive for more than eighteen years.

Iowa and Golden Crown mine.—North of Lead and just above the Black Hills and Fort Pierre Railroad is the tunnel of the Reddy mine. A great quantity of whitish siliceous ore, containing quantities of barite, was mined from small shoots that trended northwest. The workings extend through to the opposite side of the hill.

Deadwood-Terra mine.—In the Cambrian strata that lie beneath the rhyolite cap on the divide between the De Smet and Deadwood-Terra open cuts great quantities of rich siliceous ore were found resting almost directly upon the Algonkian schist. To the west lie the great chambers from which the auriferous conglomerates were mined.

Big Missouri mine.—The Big Missouri comprises two tunnels far up on the west side of the Homestake open cut and running into the decomposed dolomite of the Cambrian that here lies directly on the schists. The ore occurs in small bunches in this rock and exhibits a shell-like concentric parting. It contains extremely high values. Fractures were observed at the west end of the tunnel passing from the Cambrian rocks into the schists of the Algonkian.

Swamp Eagle mine.—On the west side of the divide, between Poorman and Bobtail gulches, is an open cut on the Swamp Eagle claim. Irregularly bounded masses of siliceous ore, carrying much barite and some wolframite, but comparatively low values in gold, were mined from this cut.

Hidden Fortune mine.—The Hidden Fortune mine, at the time it was visited, was a small open cut in the basal measures of the Cambrian, at the head of Bobtail Gulch. The ore was exposed on the surface and lay like most of the siliceous ore, almost horizontal. It contains barite, sometimes in extremely large white crystals measuring 3 inches in length. It is much oxidized, and disseminated through it in great numbers are scales and crystals of native gold. This ore is so rich that a single car of 10 tons is reported to have yielded $65,000. Considerable wolframite occurs in this ore.

Durango mine.—The Durango mine is located upon the north side of Gold Run, just above the Black Hills and Fort Pierre Railroad, with the workings of the Reddy adjoining it on the east and of the Harrison on the west. It is one of the oldest mines of the hills, being first managed by W. B. Devereux in 1877, and is still profitably worked. There are three varieties of ore—auriferous conglomerate, wolframite, and refractory siliceous. The auriferous conglomerate was first mined. It is 15 feet thick and rests directly upon the schists, probably connecting eastward with that worked in the Harrison. Devereux reports that much gold occurred free, was richest at its contact with the slates, and was often dissolved and reprecipitated in crevices in the latter rock. He reports that the richest portions of it rested on a surface inclined upward toward the west away from the lowest point of the channel. The Cambrian rocks all dip east at this point, however, and it is probable that this inclination was the result of differential movements in the Algonkian rather than a feature of the deposition of the conglomerate. Devereux reports coarse, shot-like masses of waterworn gold clinging to the under surfaces of large rounded bowlders at their point of contact with the Algonkian. Stamp milling extracted 90 to 95 per cent of this gold. These workings are now caved in. At the upper limits of this conglomerate small patches still in an unoxidized condition occur, showing pebbles embedded in a matrix of pyrite, with cavities lined with crystals of this mineral.

Above the conglomerate and in the dolomitic beds lie 8 inches to 2 feet of refractory siliceous ore which occurs in broad shoots following fractures trending generally northwest, but not often discernible in the shales above the ore. It consists of interlocking crystals of barite embedded in a matrix of secondary silica and detrital grains of quartz. It grades into wolframite in places, especially on the rims of the ore. The wolframite is granular and carries but little gold; the white baritic ore contains between $25 and $60 gold per ton. At several points in the mine the portion of the conglomerate immediately underlying the siliceous ore consists of a mass of pebbles embedded in a matrix of sand grains and secondary silica through which were scattered great quantities of native gold in sharp and branching forms.

GARDEN AREA.

Penobscot mine.—The Penobscot mine is opened by a tunnel situated on a northwestwardly projecting spur that lies to the southeast of Garden. The tunnel is upon the basal Cambrian quartzite, which dips 10° W.; it follows a shoot of siliceous ore 12 feet thick by 12 feet in maximum width, which trends N. 40° E. A strong manifold fracture may be observed in the roof. The ore lies in separate blankets of varying but rather small thickness, separated from one another by bands of unmineralized shales. The ore shows many cavities lined with crystals of jarosite and contains small quantities of barite. It is all of the oxidized type. Two minor verticals occur to the east, striking N. 54° E.

Keystone and other mines.—Southwest from the Penobscot the outcrop of basal Cambrian quartzite extends around the ridge and southward toward the divide between the northwardly flowing tributary of False Bottom Creek and Blacktail Gulch. On this outcrop are many small productive workings following fractures which trend N. 38° E., N. 45° E., N. 55° E., and N. 60° E. Ore bodies are small but often quite profitable. The largest masses occur at intersections.

Harrison mine.—Between the south tributary of False Bottom Creek and Blacktail Gulch is a divide upon which about 65 feet of Cambrian strata remain. A shaft on the center of this divide 65 feet deep constitutes the opening to the mine. There are three small ore shoots between 5 and 30 feet wide by 10 feet thick following fractures trending N. 47° E., N. 71° E., and N. 85° E. Several minor fractures trend N. 20° E. The ore bodies are largest at the intersections. Face samples of ore from this mine carried sometimes as much as $88 per ton, and the ore averaged about $30 to $35 per ton in gold, with some silver. On the hill southwest of these workings is an open cut, in which the basal quartzite is exposed, dipping northeast. Two long shoots trending N. 70° E. occur here, one of them 600 feet long. These converge at the southwest end and are intersected by a third shoot trending N. 38° E., the three forming a stope 60 feet wide.

Golden Gate mine.—The Golden Gate mine is worked by a shaft on the north side of the head of Blacktail Gulch. It is now producing a good deal of ore. The mine was inaccessible when visited.

Kicking Horse mine.—This mine is also on the north side of Blacktail Gulch, not far from the Golden Gate. It is opened by a shaft, from which a crosscut runs northwest. It is stated by the foreman that there are 9 small ore shoots in this mine, and the quartzite is strongly faulted up to the northwest at the end of the crosscut tunnel.

Blacktail (?).—Directly south of the Golden Gate shaft and on the south side of Blacktail Gulch is a mine which has produced a considerable amount of ore, but for which the writer could get no distinctive name. It is opened by four tunnels, separated from one another by slight northeast-southwest faults. There are seven small shoots following fractures, which trend N. 30° E., N. 43° E., N. 20° E., and N. 50° E. The largest stope occurs at the intersection of a system of N. 20° E., with N. 50° E. fractures.

Wells Fargo mine.—The Wells Fargo mine is located on the south side of Blacktail Gulch, west of the cross roads that lead into Tetro Gulch. There are two sets of workings, of which the western series is higher in elevation than the eastern on account of the strong easterly dip of the Cambrian strata. The western series of workings is opened by a crosscut trending southeast and comprises ten small narrow shoots that follow small fractures which trend N. 65° E. and N. 57° E., with a few minor intersecting shoots trending N. 20° E. and N. 32° E. The lower workings are east of those just described, and comprise one large shoot of ore trending N. 55° E. and three smaller shoots trending N. 47° E., N. 50° E., and N. 69° E. The fractures are very tight, and can not be seen except in the faces of ore at the end of the shoots. They do not extend into the shales that overlie the ore.

American Express mine.—The American Express mine is opened by a tunnel running northward from the bed of Sheeptail Gulch about one-half mile west of its junction with Blacktail. The workings which lie just south of those of the Wells Fargo are upon the basal Cambrian quartzite and in dolomite of the hard, blue crystalline variety. Above the ore-bearing beds about 15 feet from the quartzite is a sill of fine-grained rhyolite. The strata dip to the east at an angle of 10° to 15°. There are nine ore bodies in the mine, of which four are of considerable size. The largest is 50 feet wide at the center and was formed by four systems of fractures trending N. 40° to 45° E., N. 50° to 55° E., N. 60° to 65° E., and N. 85° E. From the east end of this large ore shoot a crosscut runs north and intersects twelve small shoots, of which three trend N. 85°; three N. 40° to 45° E.; two N. 50° to 55° E.; and four N. 60° to 65° E. The ore bodies become larger where the fractures striking N. 85° E. intersect those striking N. 40° E. The fractures passed from the ore into the overlying sill of rhyolite. All of the ore bodies in this mine except the large shoot on the east lie from 5 to 7 feet above the quartzite, the ore resting on a floor of blue dolomite of exactly the same character as the walls and immediately beneath a a roof either of fine impervious shales or of rhyolite. The ore mined was all of the sulphide variety and yielded fair average values.

YELLOW CREEK AREA.

Donelson fraction.—The Donelson fraction comprises two ore shoots, the larger following the zone of fracture with a general direction of N. 12° W. It is opened by drifts at two points; the first is a little north of the porphyry knoll which occupies the center and narrow southerly portion of the divide between Whitewood and Yellow creeks; the other is an incline a little more than 700 feet southwest of this point. About 300 feet southwest of the north opening of the mine an ore body, following a fracture whose strike is about N. 60° E., enters the main shoot. This fracture extends northeast as far as that which has produced the main ore body by which it is abruptly cut off, not appearing upon the other side. At the south end of the mine the ore body bends slightly to the southeast and divides into two portions, which trend S. 20° E., and extend into the Kickapoo claim. At the north end the fracture is of an extremely irregular form. The ore body varies from 6 to 30 feet in width and is about 14 feet in thickness. The roof is a decomposed shale; the walls are oxidized, iron-stained, and banded dolomite. The ore is reported to have yielded values averaging about $50 per ton. At many places in this mine the quartzite which underlies the ore carries from $15 to $25 per ton in gold, but is always much lower in grade than the main body of the ore.

Wasp No. 1.—Directly east of the Donelson fraction is the Wasp No. 2. Two series of ore bodies of very small size, but often of considerable length, were here mined. Fractures are completely obscured by the very decomposed character of the roof. Five of the ore shoots trend N. 45° W.; three of the longer shoots N. 33 to 38° E.; two, N. 80° E. Two small shoots trend N. 3° E., and complete the series.

Wasp No. 2, Little Blue, and Little Blue fraction.—Four hundred feet southwest of the south end of the Donelson mine are the Wasp No. 2, Little Blue, and Little

Blue fraction, while south of these mines a short distance are the Wasp No. 4 and Minnie mines. The workings of all these mines are connected with one-another. The ore lies directly upon the quartzite, and except in certain portions of the Minnie mine carried high values. The shoots vary from 5 to 40 feet in width and are generally 5 to 6 feet in thickness. In all but a few cases the roof is a much decomposed shale. Lagging has generally obscured the fractures, but the ore bodies trend generally N. 37° to 40° E. There are minor ore bodies striking north and south and N. 12° W. A few other shoots are present which follow directions undetermined. Quantities of barite occur in the ore, and irregular porphyry dikes are found with considerable frequency.

In the Wasp No. 2 mine a large irregular porphyry mass, striking slightly west of north, faults the Cambrian about 20 feet. As it proceeds toward the south it becomes divided into two dikes, on the west side of either of which is a fault with a small downthrow of about 8 or 10 feet. Between these two dikes is a small stope about 40 feet wide and 60 feet in length. One of the porphyry dikes curves up over the ore so that the space is almost entirely inclosed in porphyry. This small body of ore is reported to have yielded $75,000. From several of these mines deposits of granular wolframite were mined. It occurs in nodules and as rims to the main body of the ore. In one case the wolframite was observed forming kidney-shaped masses in the decomposed dolomite beds a few inches from the quartzite. Much of this is reported to have contained high values in gold, and was shipped to the smelter and treated for that mineral before its value as an ore of tungsten was recognized.

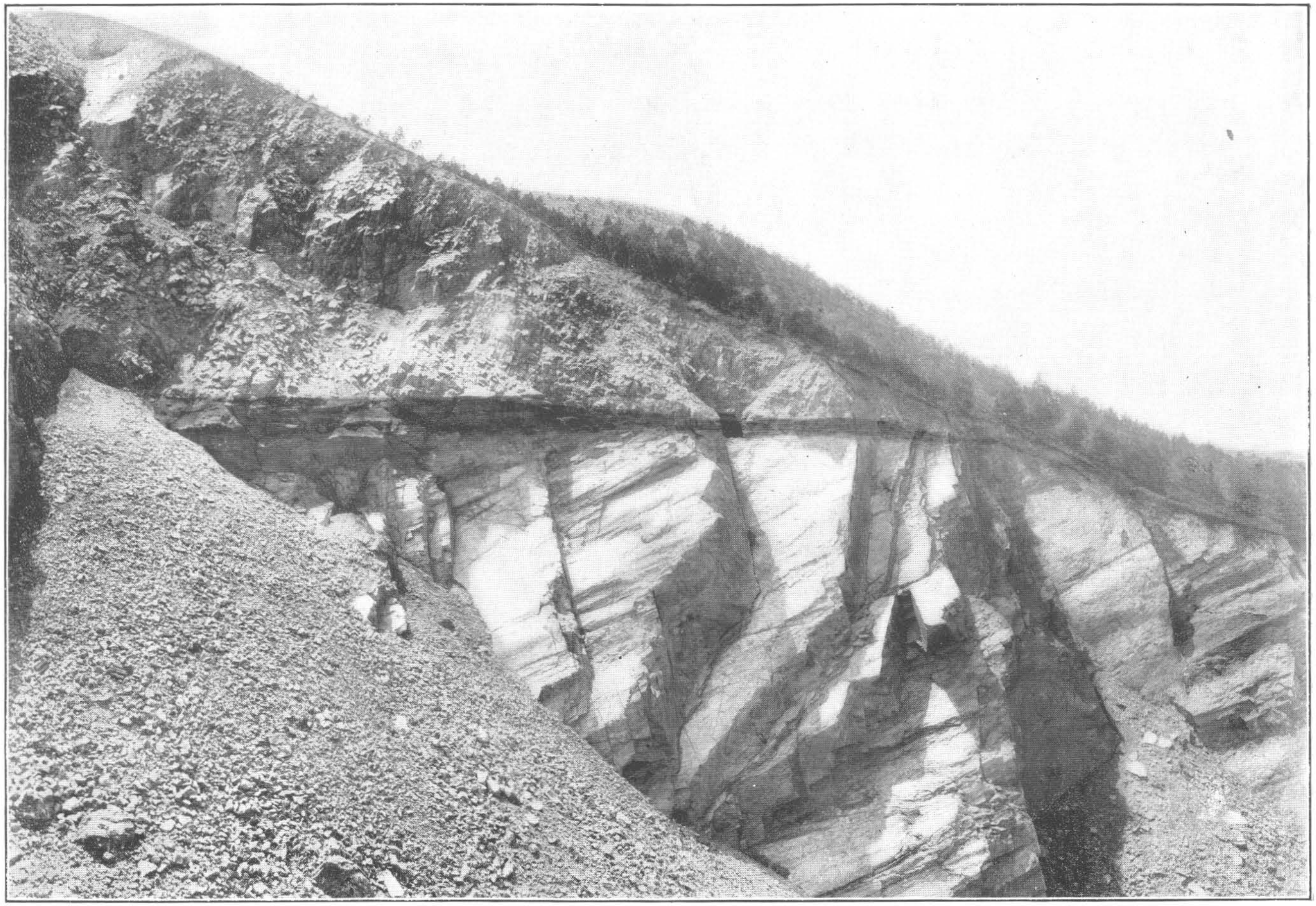
Two Strike and Little Pittsburg mines.—These mines have yielded but small quantities of siliceous ore and are more important in connection with the tungsten deposits discussed on page 164. The ore lies on the basal quartzite and carries barite and quantities of granular wolframite, which itself contains radiating crystals of barite and cavities lined with scheelite. Some of the siliceous ore contains long, acicular crystals of stibnite radiating from a center like the spicules of a radiolarian.

SQUAW CREEK AREA.

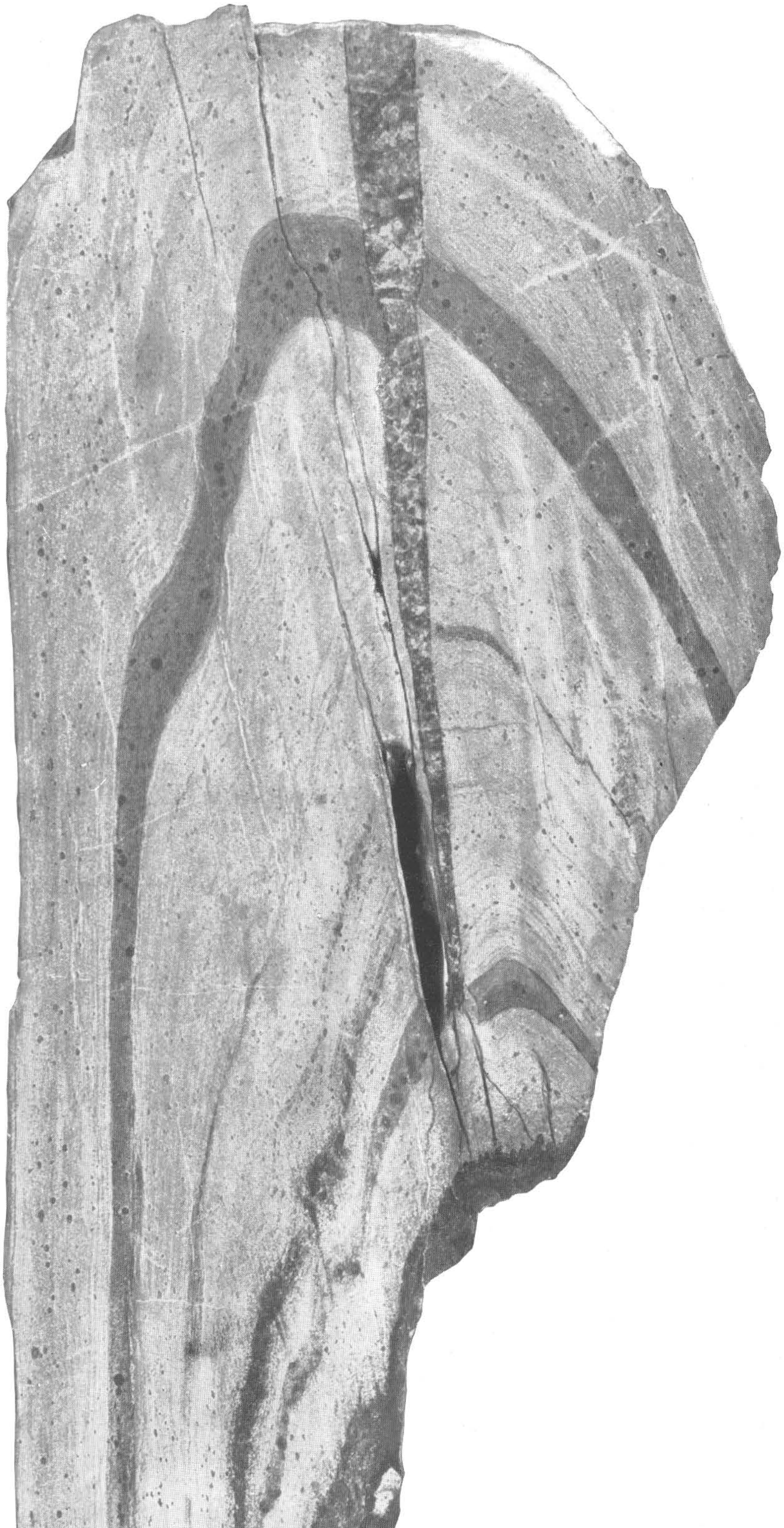
Cleopatra mine.—The Cleopatra mine is situated on Squaw Creek, just above its junction with Spearfish Creek. The ore occurs as a replacement of dolomite along fractures which strike nearly east and west. There were some small bodies of flat siliceous ore opened at the time the mine was visited, but no large ore shoots were discovered. Since this report was written this mine has become an important producer. See page 152.

PLATES II TO XX.

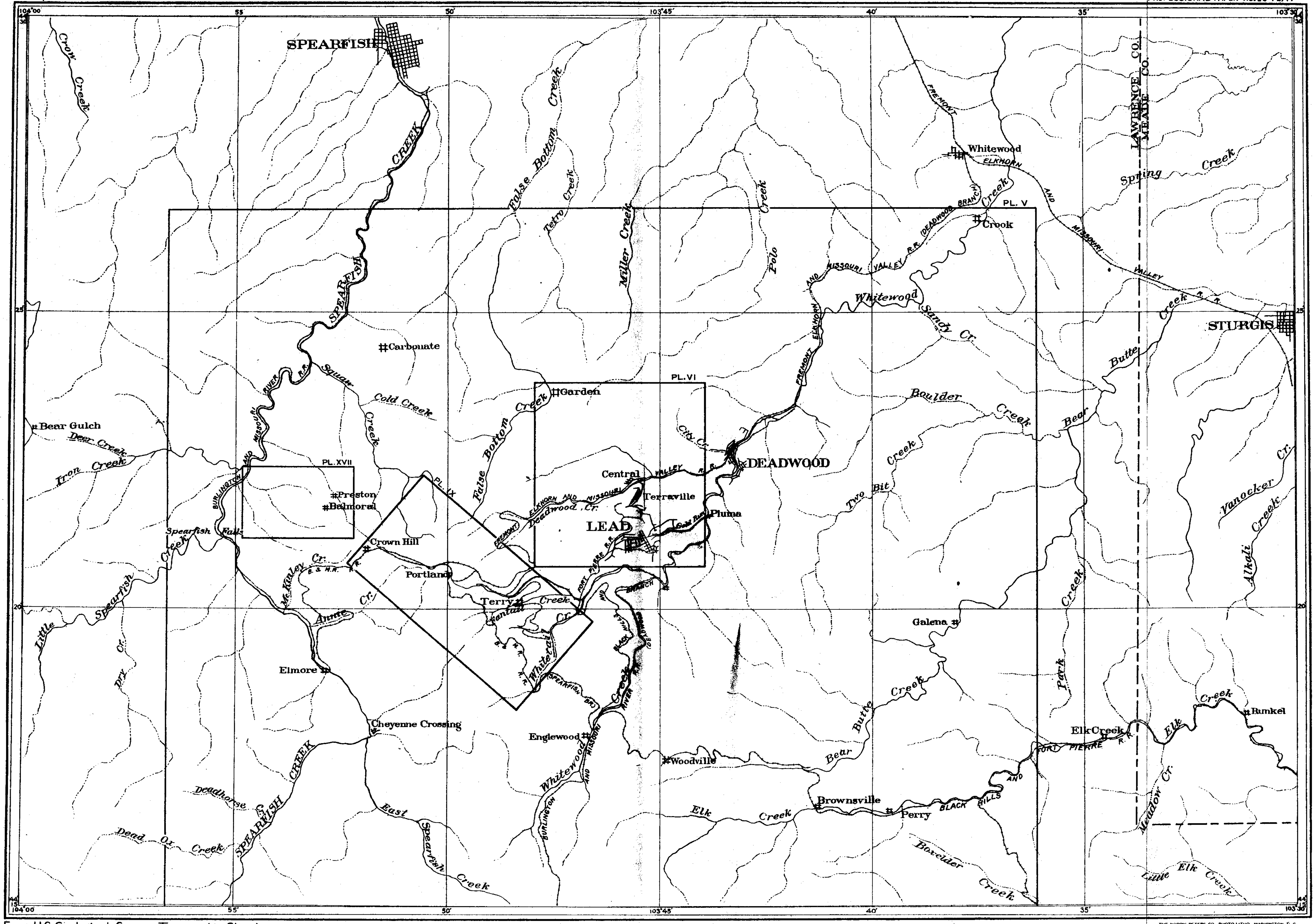
PLATES II TO XX.



SOUTHERN DEADWOOD-TERRA OPEN CUT.



SPECIMEN OF SLATE SHOWING RELATION OF FOLDING TO LAMINATION.



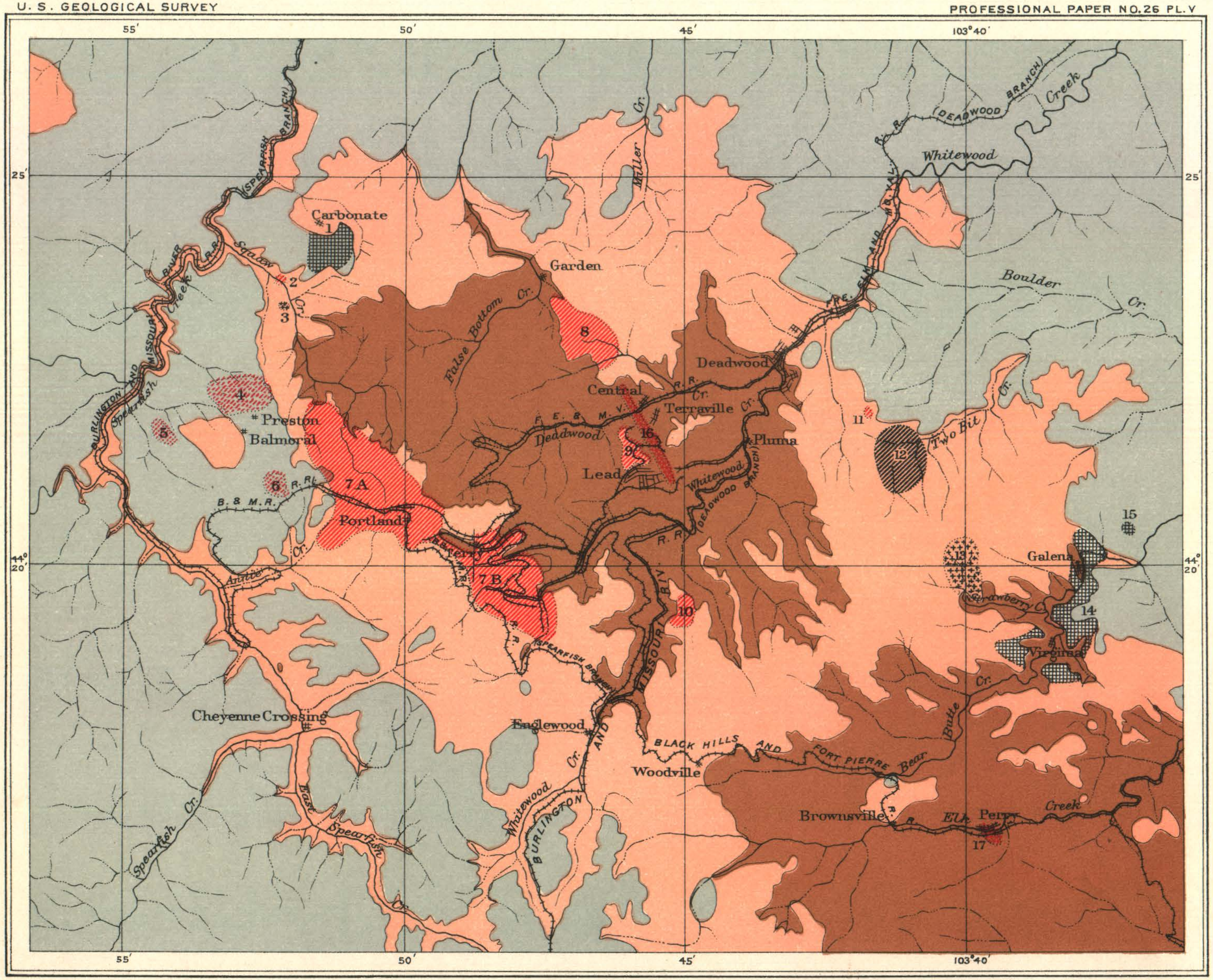
From U.S.Geological Survey Topographic Sheets

SKETCH MAP OF A PORTION OF THE NORTHERN BLACK HILLS

SHOWING THE LOCATION OF THE SEVERAL SPECIAL MAPS INCLUDED IN THIS PAPER

Scale

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D.C.



A. HOEN & CO. BALTIMORE.

LEGEND OF PRODUCTIVE AREAS

▨ Productive areas of refractory siliceous ores of Cambrian

▨ Productive areas of gold-bearing lodes in the Algonkian

▦ Productive areas of lead-silver ores

▨ Productive areas of refractory siliceous ores of the Carboniferous limestone

▨ Area of pyritous ores

▦ Miscellaneous *(includes chiefly ores occurring in irregular fractures in igneous rocks)*

LEGEND OF GEOLOGY

■ Post-Cambrian *(Carboniferous limestones in great part)*

■ Cambrian containing much porphyry

■ General Algonkian containing much porphyry

NAMES OF AREAS

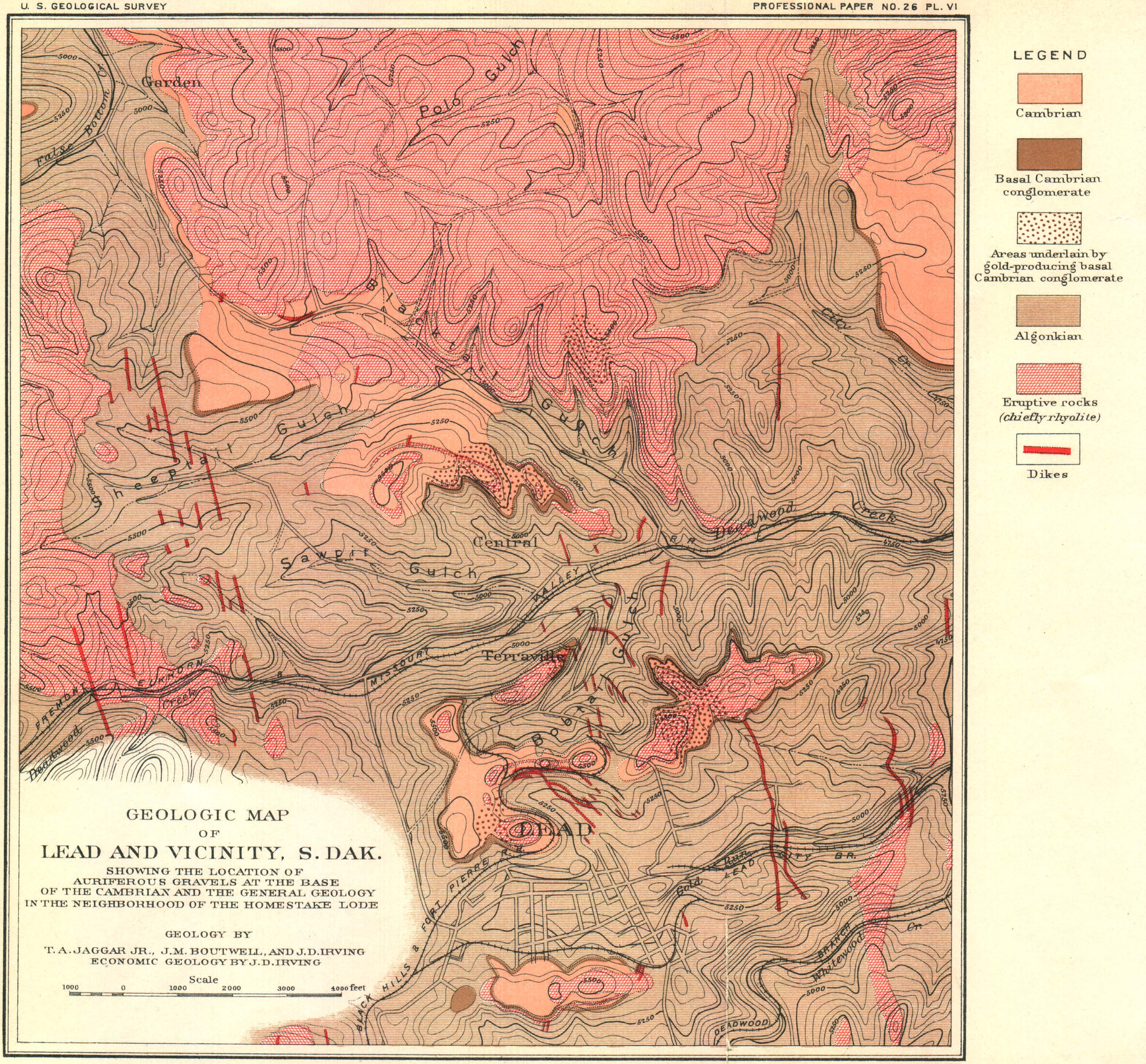
1 Carbonate area
2 Squaw Creek area
3 Area of prospects of sylvanite
4, 5 } Ragged Top area
6 Elk Mountain area
7 Bald Mountain area
  A. Portland district
  B. Ruby Basin district
8 Garden area
9 Lead City area
10 Yellow Creek area
11 Spruce Gulch area
12 Two Bit Creek area
13 Strawberry Gulch area
14, 15 } Galena district
16 Homestake area
17 Cloverleaf area (Uncle Sam)

MAP OF THE NORTHERN BLACK HILLS

SHOWING GEOLOGIC STRUCTURE AND THE LOCATION AND RELATION OF THE VARIOUS PRODUCTIVE MINING AREAS TO THIS STRUCTURE

BY J. D. IRVING

Scale
3/4 1/2 1/4 0 1 2 3 4 5 miles

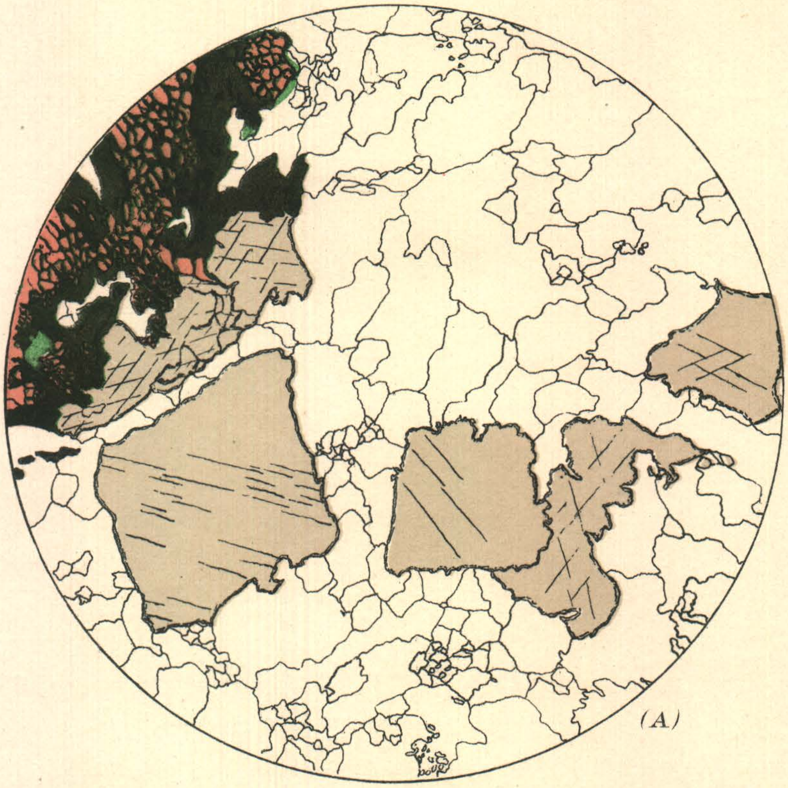


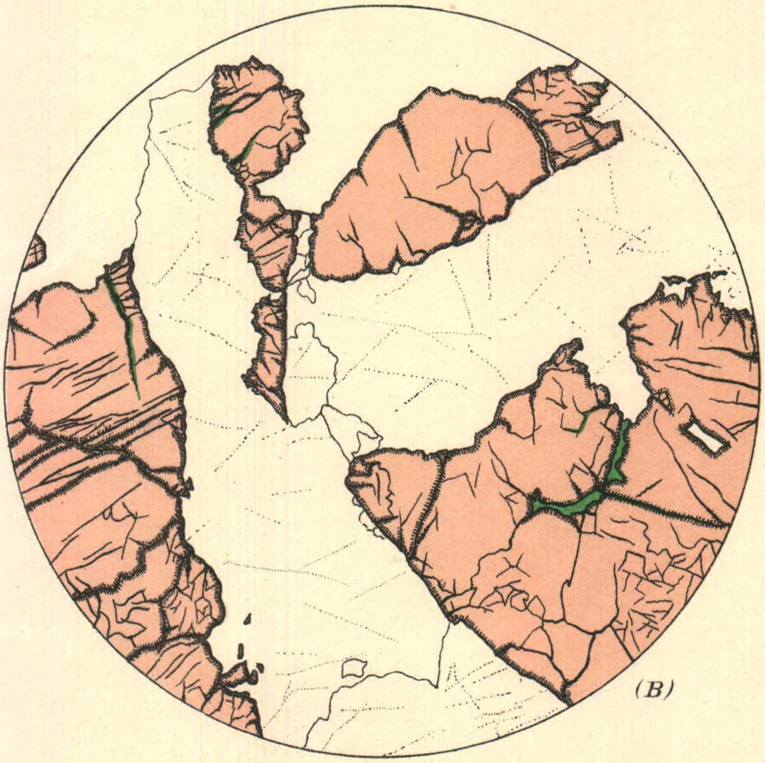
GEOLOGIC MAP OF LEAD AND VICINITY, S. DAK.

SHOWING THE LOCATION OF AURIFEROUS GRAVELS AT THE BASE OF THE CAMBRIAN AND THE GENERAL GEOLOGY IN THE NEIGHBORHOOD OF THE HOMESTAKE LODE

GEOLOGY BY
T. A. JAGGAR JR., J. M. BOUTWELL, AND J. D. IRVING
ECONOMIC GEOLOGY BY J. D. IRVING

A. HOEN & CO. BALTIMORE.





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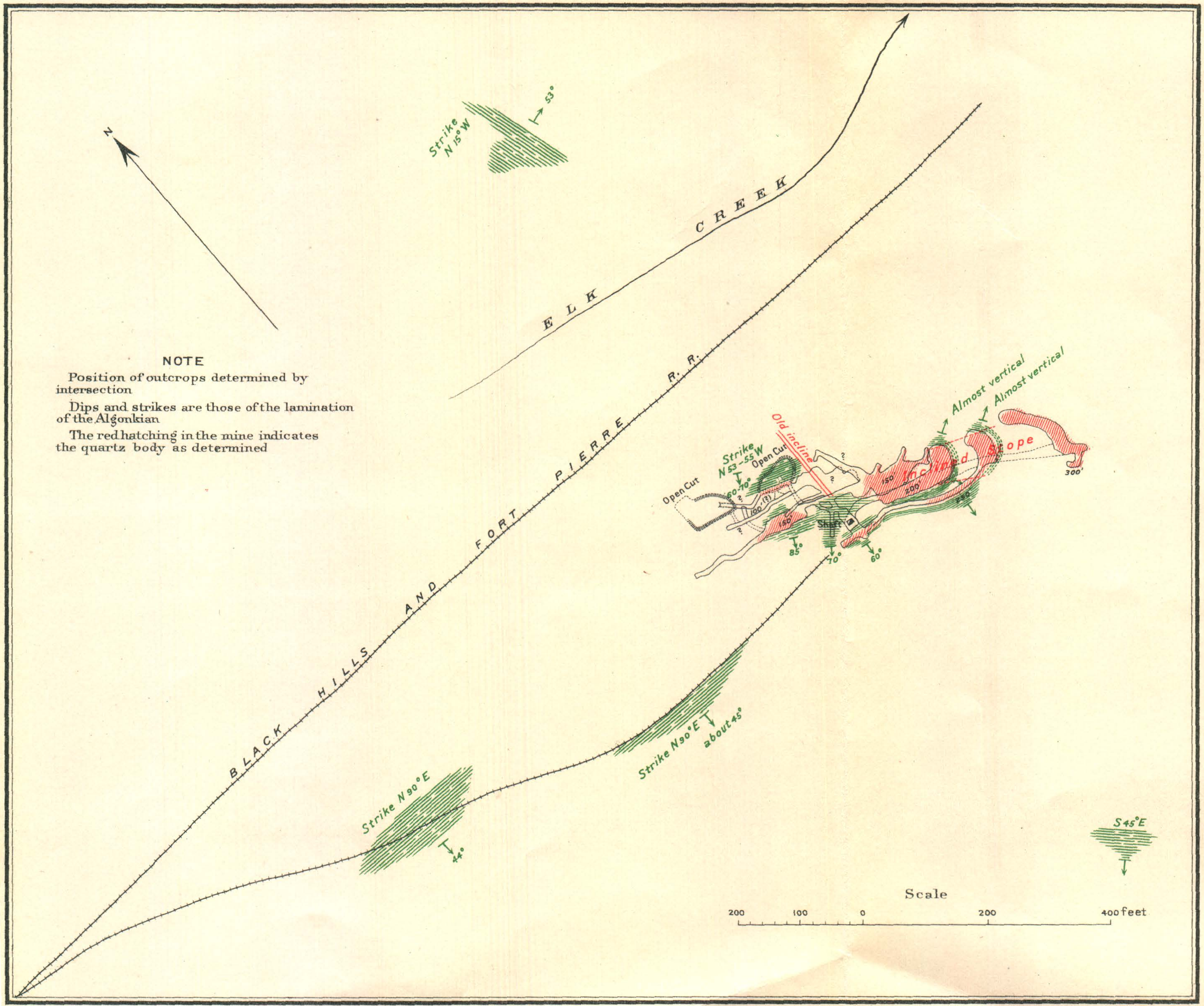
THIN SECTIONS OF HOMESTAKE ORE



NOTE

Position of outcrops determined by intersection

Dips and strikes are those of the lamination of the Algonkian

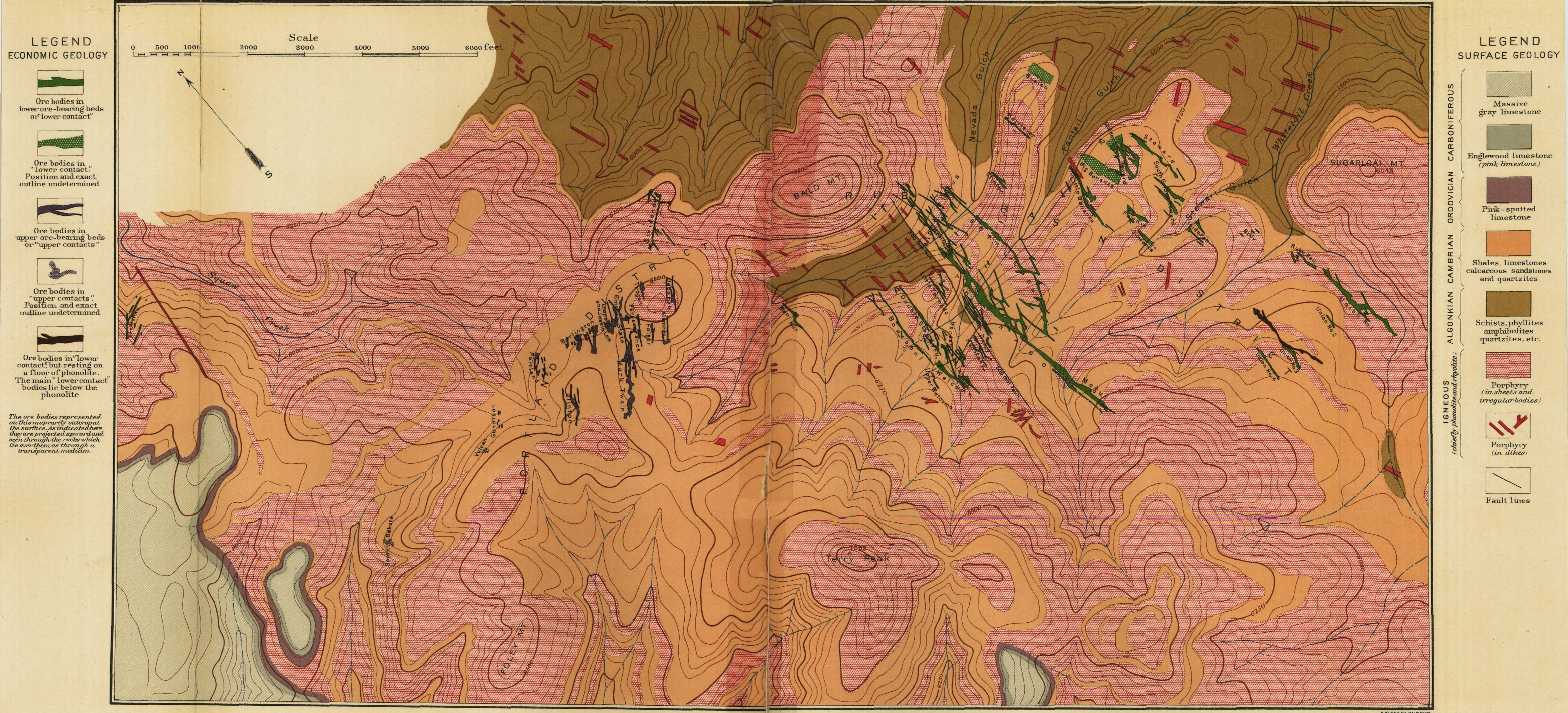
The red hatching in the mine indicates the quartz body as determined

A. HOEN & CO. BALTIMORE

SKETCH MAP OF THE CLOVERLEAF MINE

BLACK HILLS, SOUTH DAKOTA

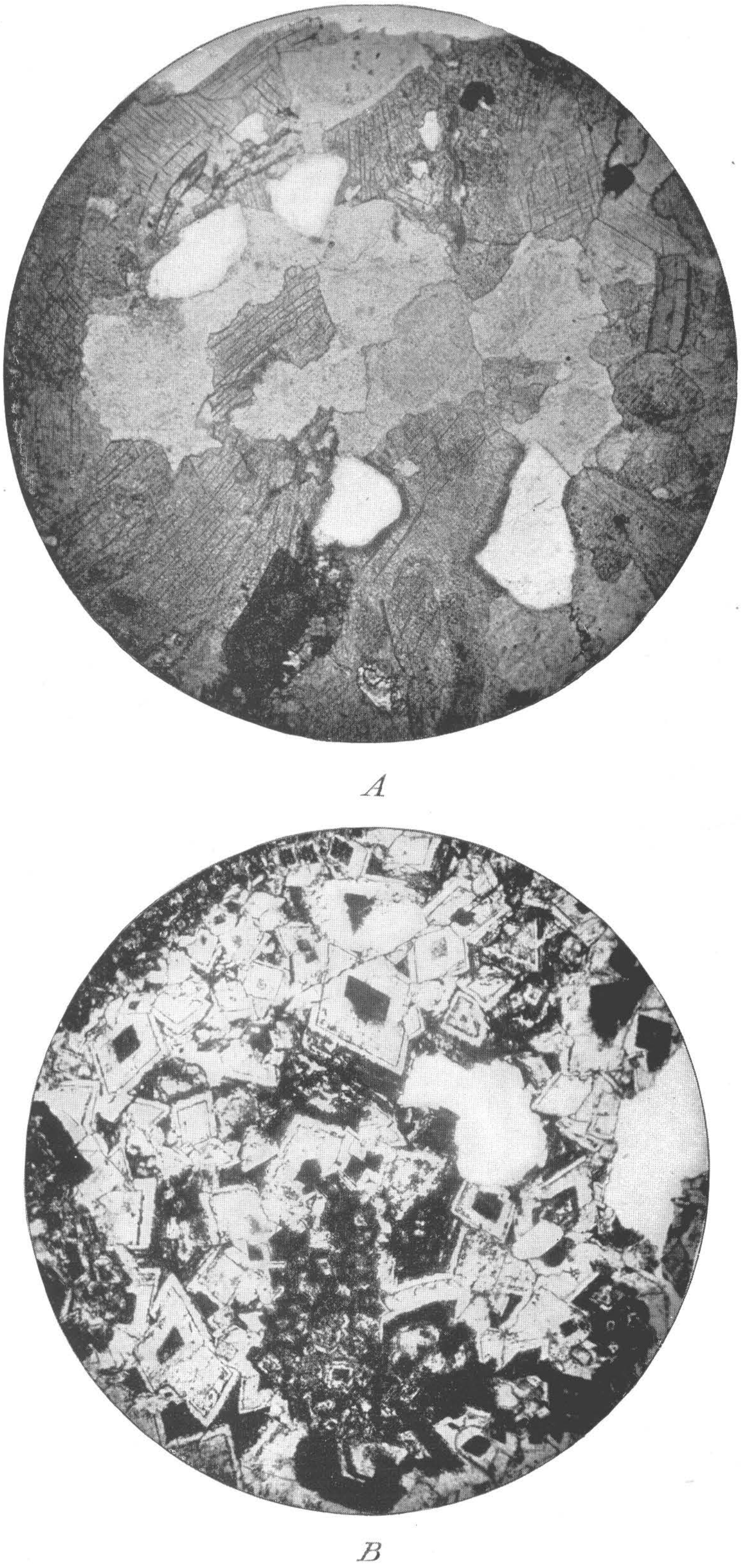
SHOWING ITS RELATION TO THE SURFACE GEOLOGY


LEGEND
ECONOMIC GEOLOGY
Ore bodies in lower ore-bearing beds or "lower contact"
Ore bodies in "lower contact." Position and exact outline undetermined
Ore bodies in upper ore-bearing beds or "upper contacts"
Ore bodies in "upper contacts." Position and exact outline undetermined
Ore bodies in "lower contact," but resting on a floor of phonolite. The main "lower contact" bodies lie below the phonolite
The ore bodies represented on this map rarely outcrop at the surface. As indicated here they are projected upward and seen through the rocks which lie over them as through a transparent medium
Scale
0 500 1000 2000 3000 4000 5000 6000 feet
N
S
BALD MT.
RUBY BASIN DISTRICT
PORTLAND DISTRICT
Squaw Creek
Nevada Gulch
Fantail Gulch
Stewart Gulch
Whitetail Creek
SUGARLOAF MT.
Terry Peak
FOLEY MT.
300 foot fault
Big Bonanza
Little Bonanza
Reward
South Golden Reward
Steward
Fannie
Sundance
Mogul
Ben Hur
Boscobel
Double Standard
Little Tornado
Hardscrabble
Upper Welcome
Welcome
Harmony
Darcy
Clinton
Trojan
Dakotah
Alameda
Folger
Perseverance
State
Empire
Leopard and Jessie Lee
Burlington
Portland
Mark Twain
Gunnison
Vulcan
South Dakota
Union No 2
6000
6250
6500
LEGEND
SURFACE GEOLOGY
CARBONIFEROUS
Massive gray limestone
Englewood limestone (pink limestone)
ORDOVICIAN
Pink-spotted limestone
CAMBRIAN
Shales, limestones calcareous sandstones and quartzites
ALGONKIAN
Schists, phyllites amphibolites quartzites, etc.
IGNEOUS (chiefly phonolite and rhyolite)
Porphyry (in sheets and irregular bodies)
Porphyry (in dikes)
Fault lines
A. HOEN & CO. BALTIMORE

MAP SHOWING THE PRINCIPAL SHOOTS OF REFRACTORY SILICEOUS ORE IN THE BALD MOUNTAIN AREA AND THEIR RELATION TO THE SURFACE GEOLOGY

BY J. D. IRVING

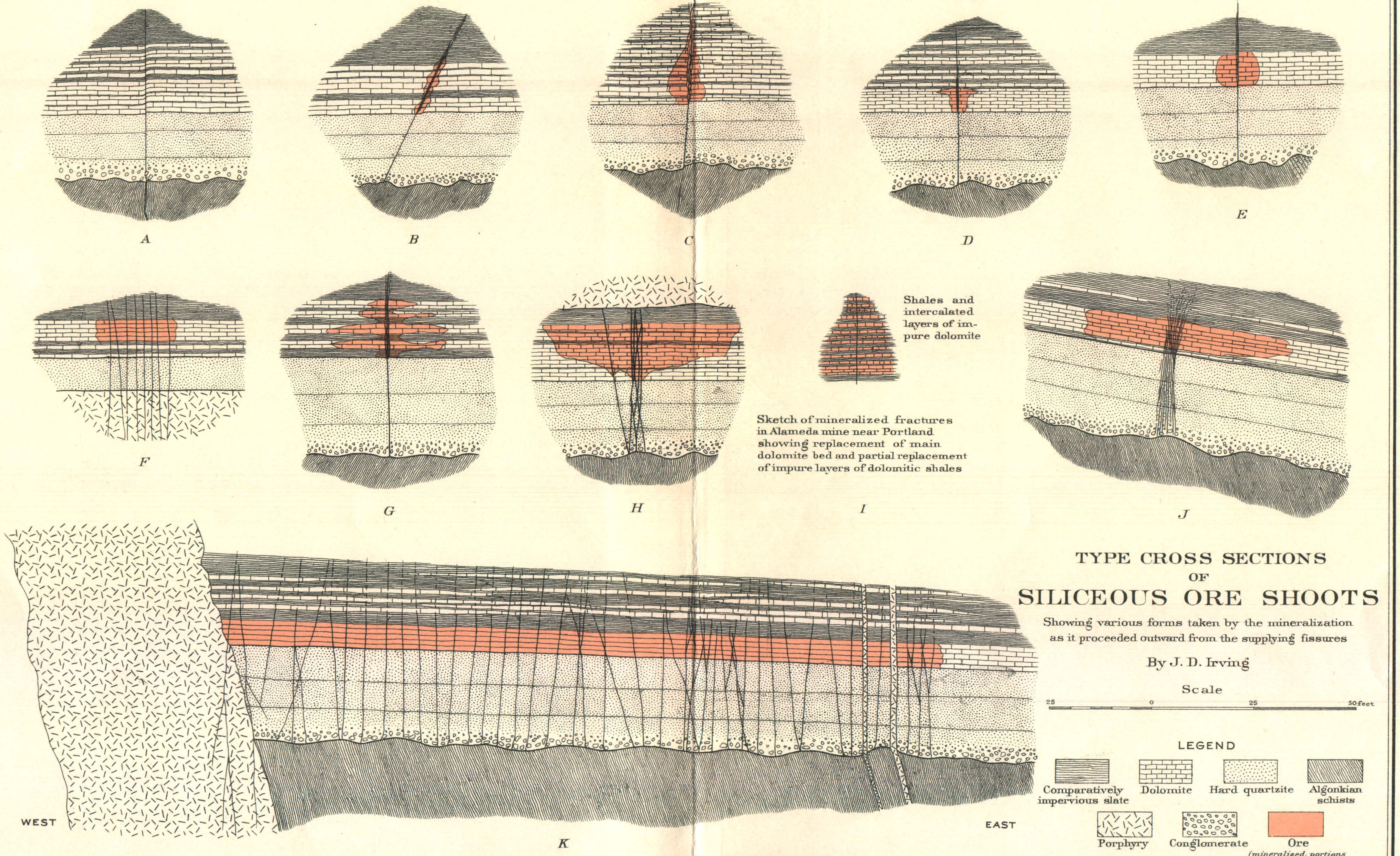
1903



DOLOMITE, OR ORE-BEARING ROCK.

A. Xenomorphic variety. Shows cleavage of the dolomite, which forms the greater part of the rock; also grains of detrital quartz. Analysis on page 121.

B. Automorphic variety. Shows complete rhombs or crystals of dolomite, of which the rock is made up. This structure may be seen preserved in the ore shown in Pl. XV, *A*.

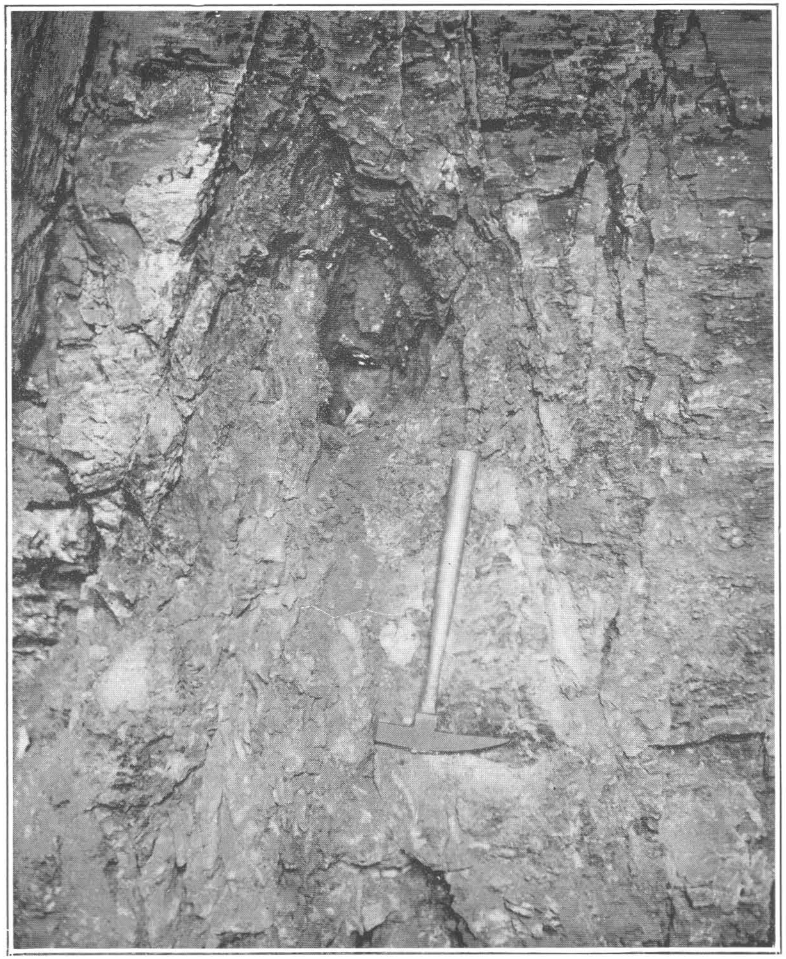

A
B
C
D
E
F
G
H
Shales and intercalated layers of impure dolomite
Sketch of mineralized fractures in Alameda mine near Portland showing replacement of main dolomite bed and partial replacement of impure layers of dolomitic shales
I
J
WEST
EAST
K
Scale
25
0
25
50 feet
LEGEND
Comparatively impervious slate
Dolomite
Hard quartzite
Algonkian schists
Porphyry
Conglomerate
Ore (mineralized portions of the country rock)

TYPE CROSS SECTIONS OF SILICEOUS ORE SHOOTS

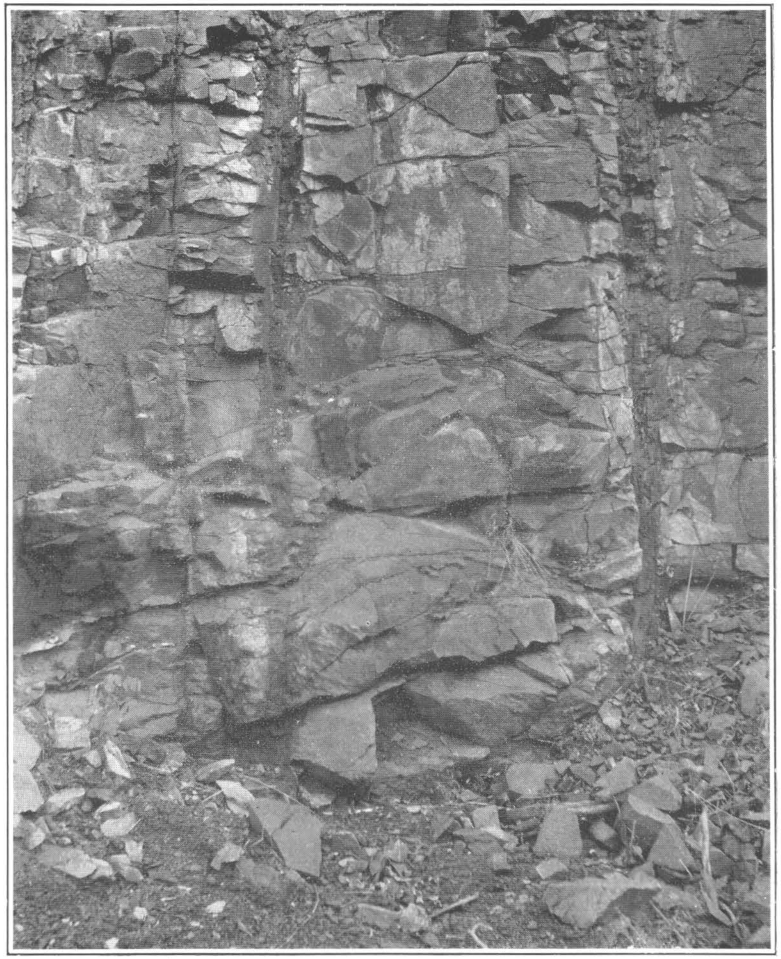
Showing various forms taken by the mineralization as it proceeded outward from the supplying fissures

By J. D. Irving

A. HOEN & CO. BALTIMORE.



A. COMPOSITE FRACTURE OR "VERTICAL," AS SEEN IN OPEN CUT OF THE CLEOPATRA MINE, SQUAW CREEK.

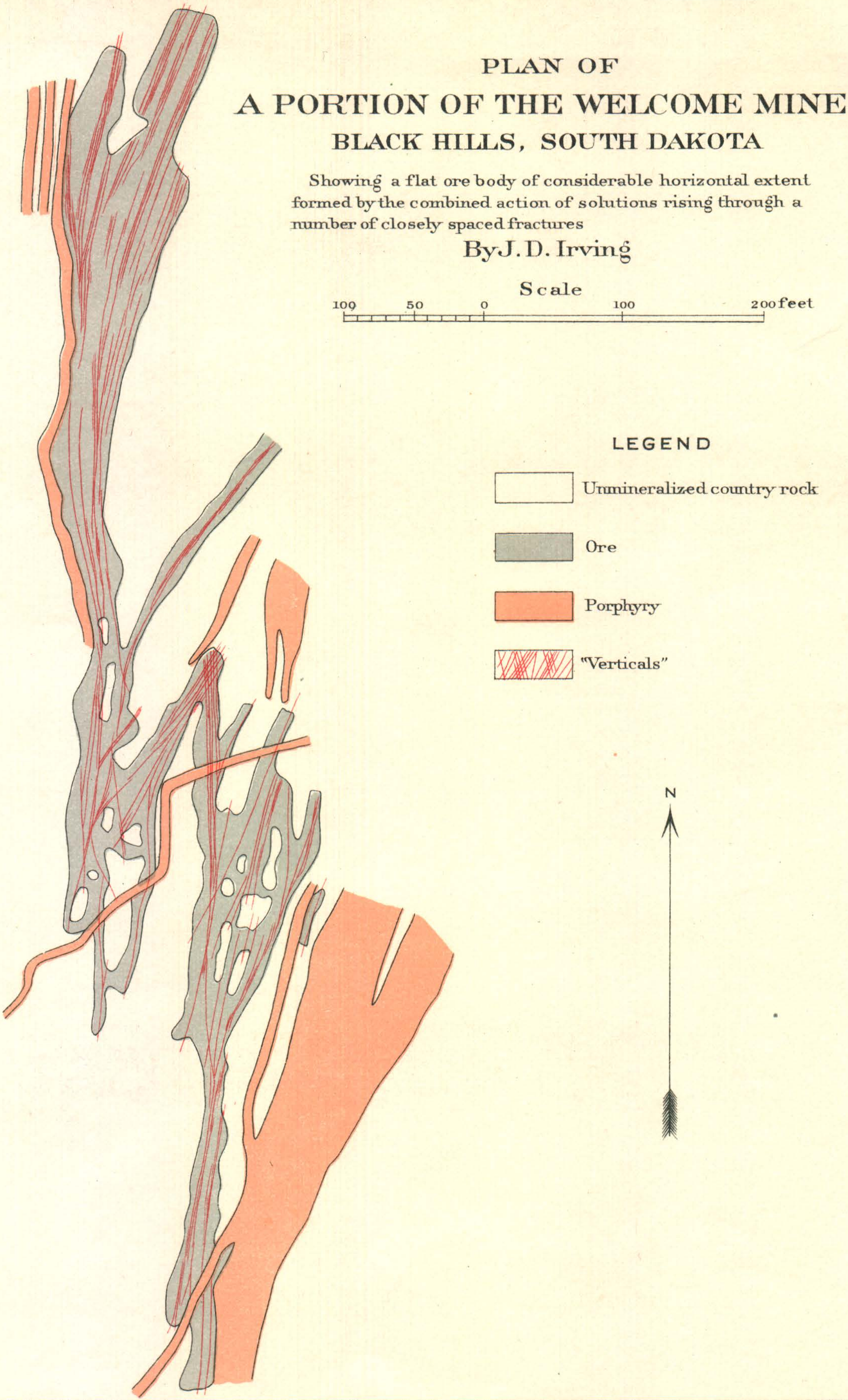


B. MINERALIZED FRACTURES OR "VERTICALS" IN PORPHYRY NEAR THE MOUTH OF THE LITTLE BONANZA MINE, ON SOUTH SIDE OF FANTAIL GULCH.

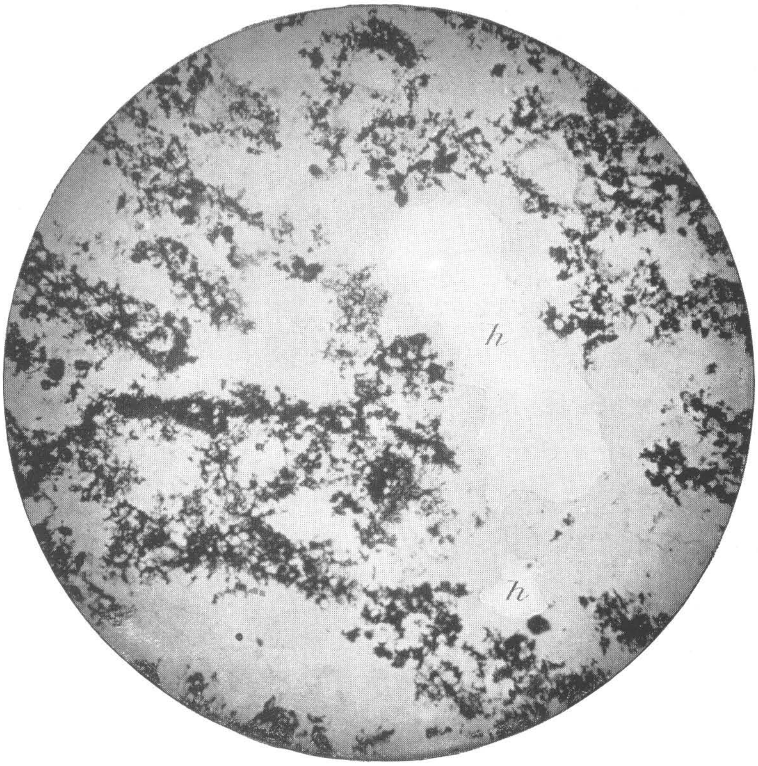
PLAN OF
A PORTION OF THE WELCOME MINE
BLACK HILLS, SOUTH DAKOTA

Showing a flat ore body of considerable horizontal extent formed by the combined action of solutions rising through a number of closely spaced fractures

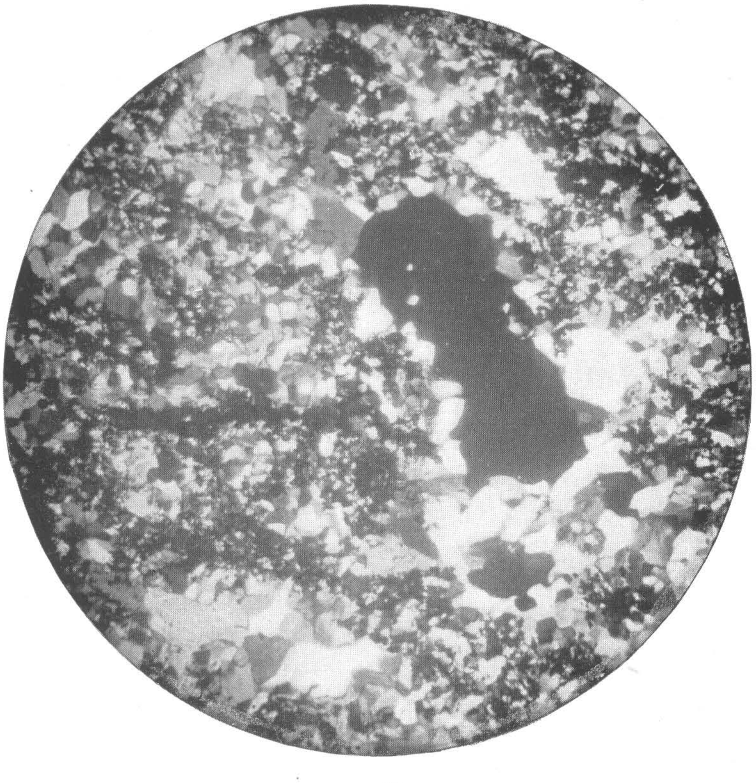
By J. D. Irving



A. HOEN & CO. BALTIMORE.



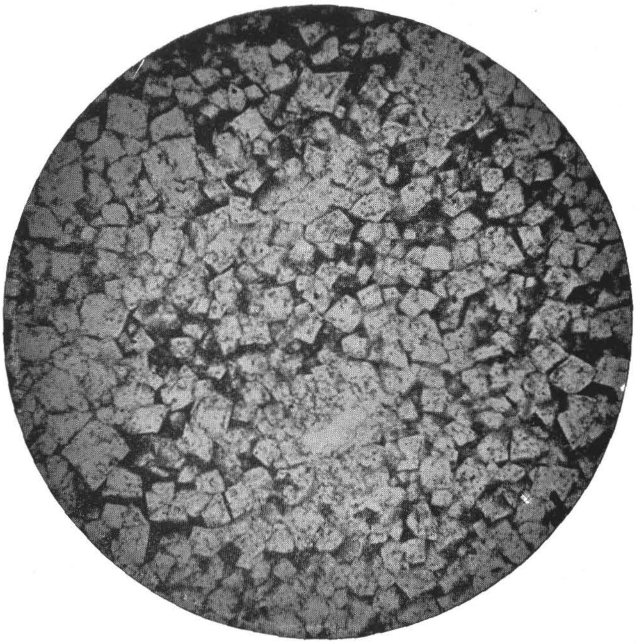
A



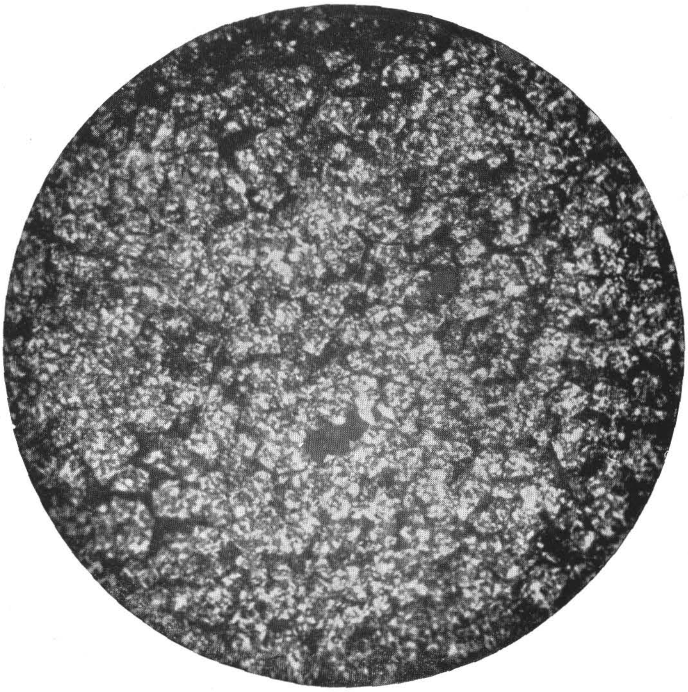
B

SILICEOUS ORE FROM THE ROSS-HANNIBAL MINE.

A. Seen without the polarizer. Shows the dark mineral, pyrite, and the light mineral, quartz (*h*).
B. Seen with the polarizer. Shows the separate individuals of silica forming the ore.



A

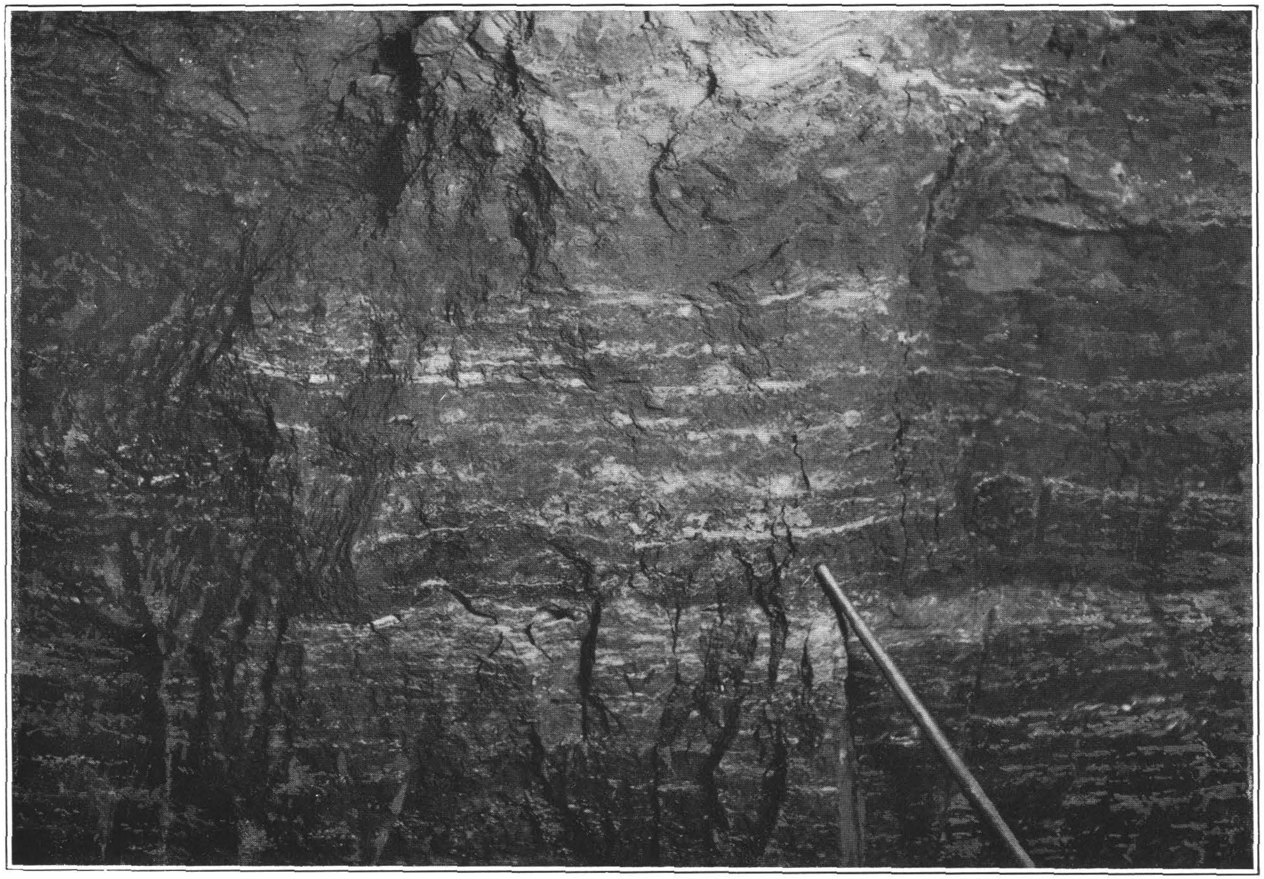


B

SILICEOUS ORE.

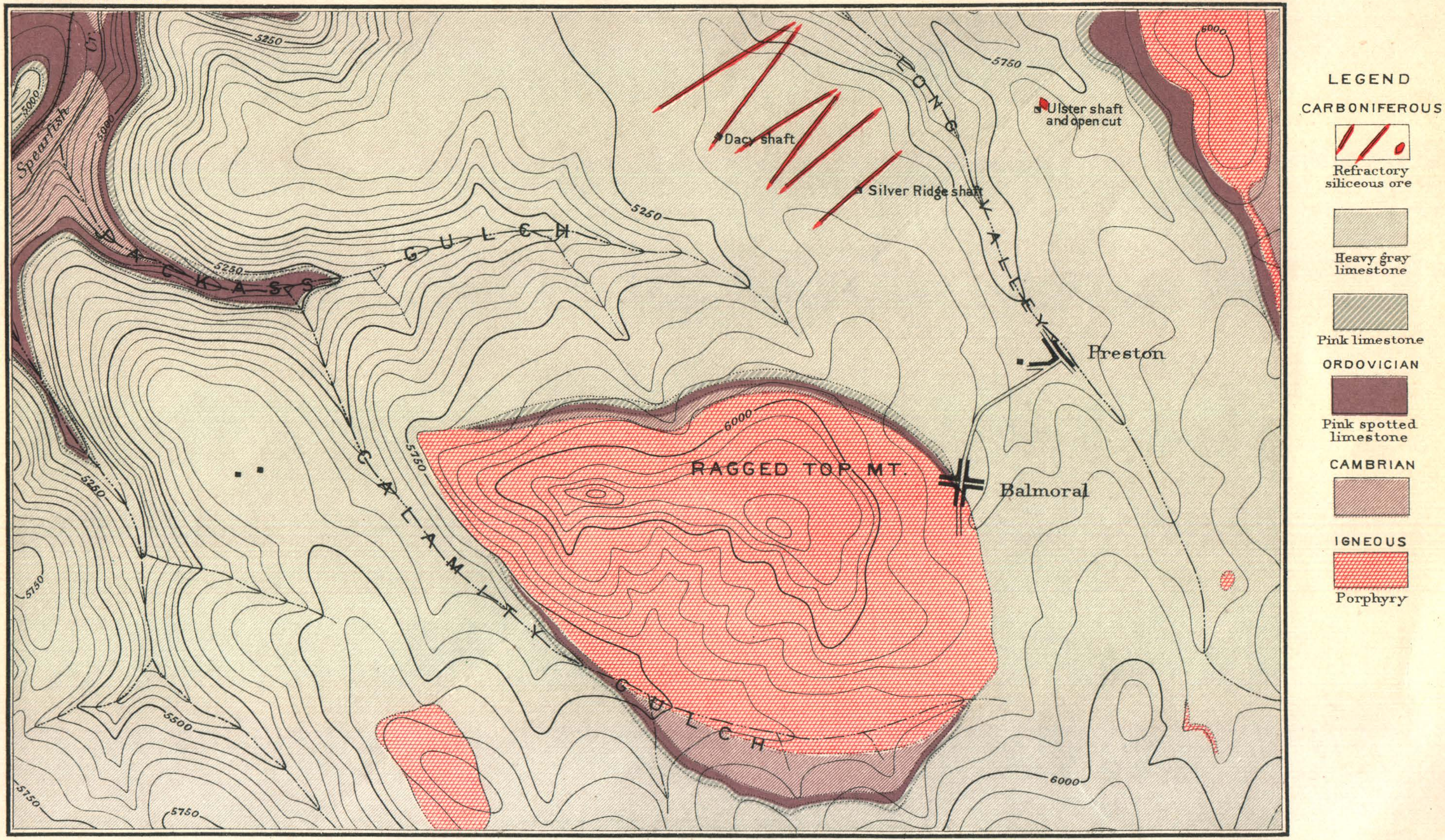
A. Seen without the polarizer. Shows the perfect preservation of the form of the dolomite rhombs after complete replacement by silica.

B. Seen with the polarizer. Shows that the rock is completely changed to silica.



BANDED SILICEOUS ORE, NO. 2 SHOOT, UNION MINE.

Shows the preservation of sedimentary bedding in the ore, the banding here seen being continuous with that of the inclosing stratified rocks.



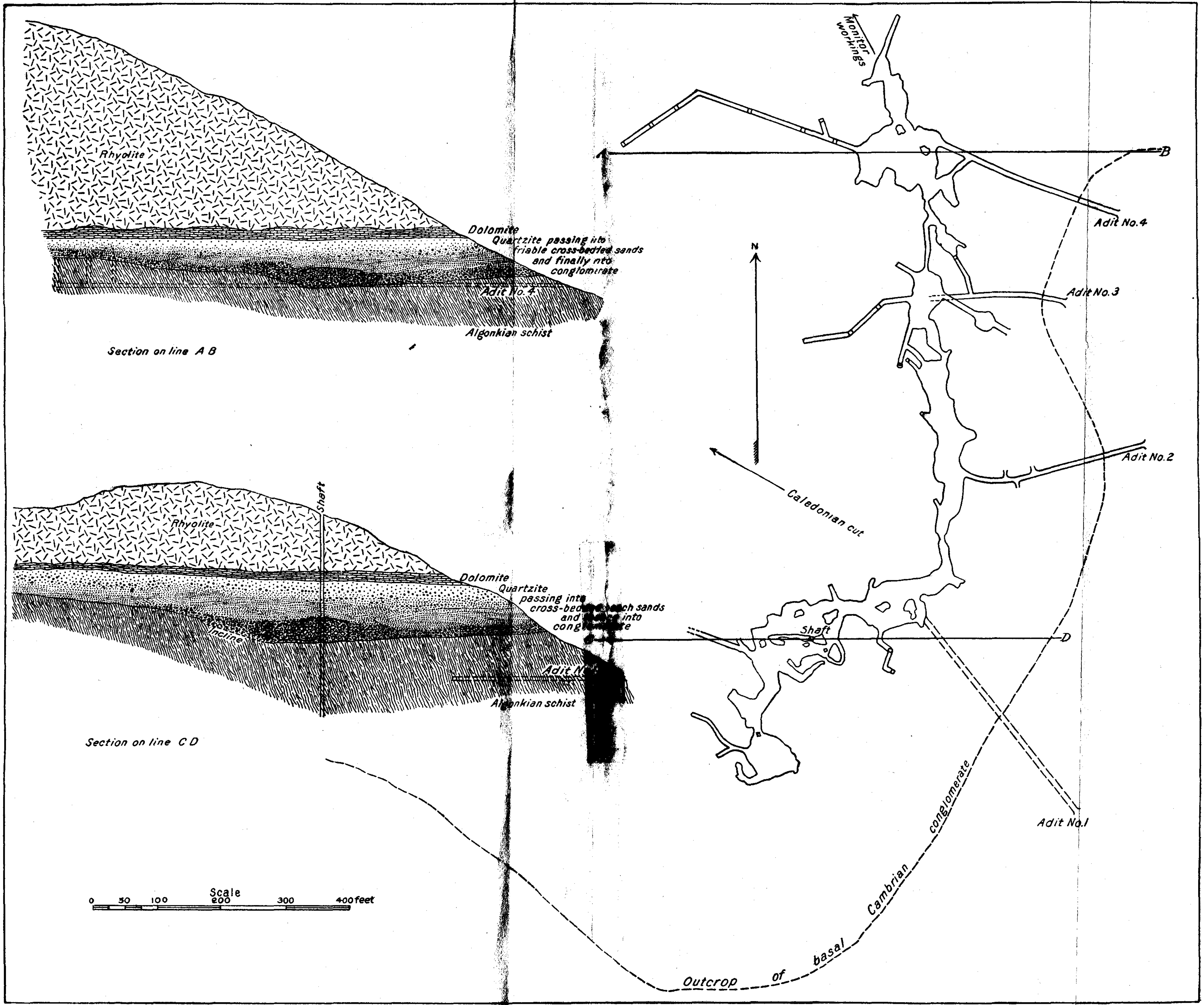
A. HOEN & CO. BALTIMORE.

MAP OF RAGGED TOP MOUNTAIN AND VICINITY, BLACK HILLS, S. DAK.

SHOWING THE GEOLOGY, POSITION, AND DIRECTION OF THE MAIN RAGGED TOP "VERTICALS" OR SILICEOUS GOLD VEINS, IN THE CARBONIFEROUS LIMESTONE; ALSO THE LOCATION OF THE ULSTER MINE

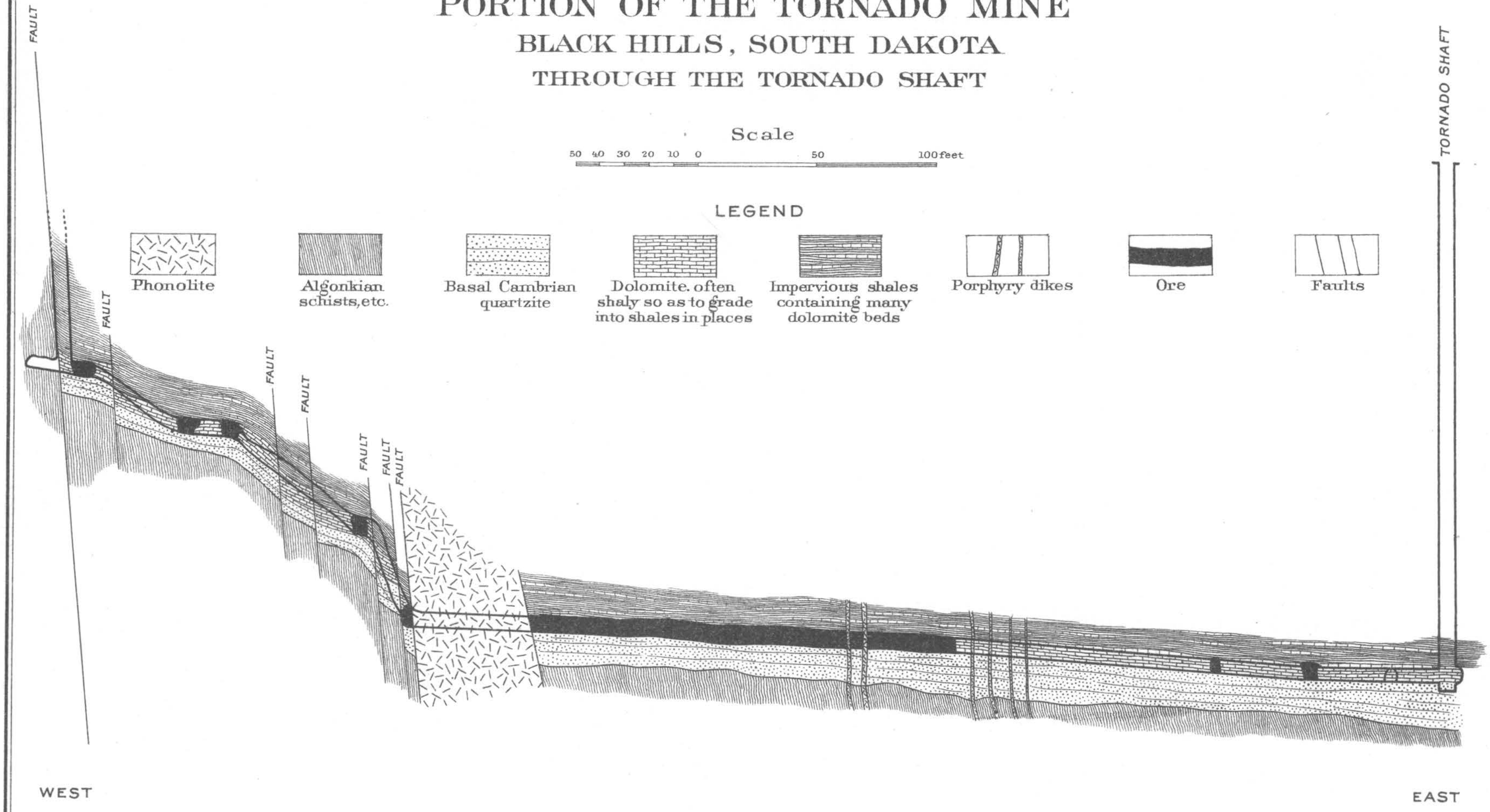
Scale

0 500 1000 2000 3000 4000 feet


Rhyolite
Dolomite
Quartzite passing into friable cross-bedded sands and finally into conglomerate
Adit No. 4
Algonkian schist
Section on line A B
Shaft
Rhyolite
Dolomite
Quartzite passing into cross-bedded beach sands and [illegible] into conglomerate
Incline
Adit No.
Algonkian schist
Section on line C D
Scale
0 50 100 200 300 400 feet
Monitor workings
A
B
Adit No. 4
N
Adit No. 3
Adit No. 2
Caledonian cut
Shaft
C
D
Adit No. 1
Outcrop of basal Cambrian conglomerate

PLAN AND CROSS SECTION OF THE HAWKEYE-PLUMA MINE, SHOWING THE GEOLOGICAL RELATIONS OF THE GOLD-BEARING CAMBRIAN CONGLOMERATE.

CROSS SECTION OF
PORTION OF THE TORNADO MINE
BLACK HILLS, SOUTH DAKOTA
THROUGH THE TORNADO SHAFT



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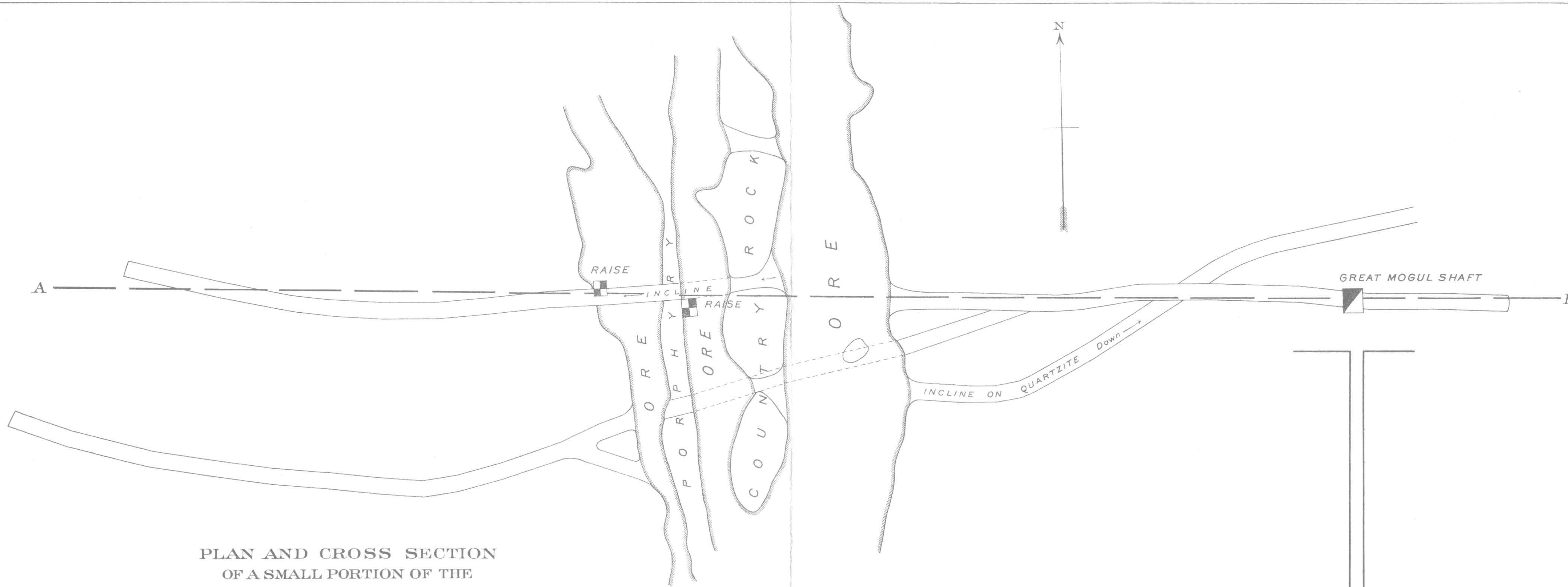
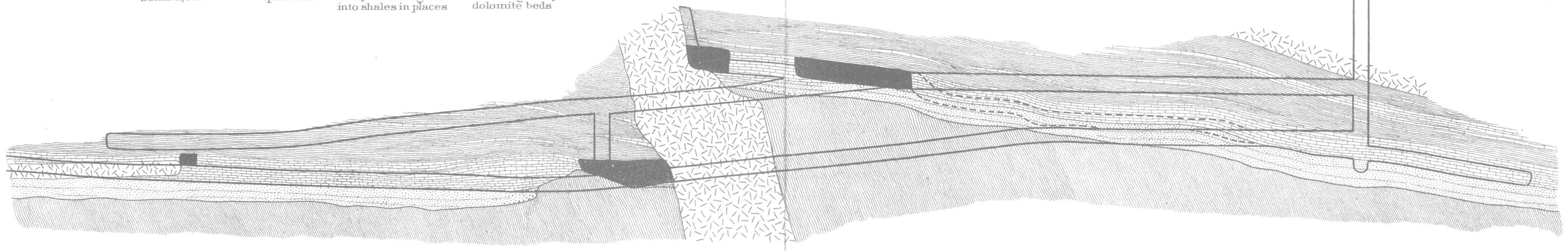


PLAN AND CROSS SECTION OF A SMALL PORTION OF THE GREAT MOGUL MINE BLACK HILLS, SOUTH DAKOTA

Scale
50 40 30 20 10 0 50 100 feet

LEGEND

Phonolite	Algonkian schists, etc.	Basal Cambrian quartzite	Dolomite, often shaly so as to grade into shales in places	Impervious shales containing many dolomite beds	Ore



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[Professional Paper No. 26.]

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