DEPARTMENT OF THE INTERIOR
HUBERT WORK, Secretary

U. S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Bulletin 765

GEOLOGY OF THE REGION AROUND LEAD SOUTH DAKOTA

AND ITS BEARING ON THE HOMESTAKE ORE BODY

BY

SIDNEY PAIGE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1924

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
20 CENTS PER COPY

CONTENTS

ILLUSTRATIONS

GEOLOGY OF THE REGION AROUND LEAD, S. DAK., AND ITS BEARING ON THE HOMESTAKE ORE BODY

By Sidney Paige

INTRODUCTION

The following account of the geology in the vicinity of the Homestake ore body sets forth part of the results of a more general study of the geology and mineral resources of the Black Hills of South Dakota.[1] The first systematic geologic investigation of the Homestake mine was undertaken by J. D. Irving and S. F. Emmons, and the results of their studies were published in 1904.[2] This investigation did not include the deeper workings of the Homestake mine, for in 1899, during the progress of the work, the managers withdrew permission to study them.

In 1912, while I was engaged in a general examination of the pre-Cambrian rocks of the Black Hills, I obtained permission from Mr. T. J. Grier to make a rapid underground reconnaissance, to discover evidence in support of a new hypothesis regarding the origin of the ore—a hypothesis based on surface studies of the pre-Cambrian stratigraphy and structure. The result of this reconnaissance was published in a short paper in 1913.[3] The managers did not desire further work at that time. Although brief, this examination served to support the hypothesis formulated from a study of the surface, and the facts presented and ideas advanced were in some respects so at variance with those set forth by Emmons and Irving that it was desirable to make a more thorough examination should opportunity permit. This opportunity was afforded through the courtesy of the superintendent, Mr. B. C. Yates, in the spring of 1920, it being understood that the study would be concerned solely with the "nature and origin of the ore body." The present paper is therefore confined strictly to that subject. It is much to be desired

[1] Darton, N. H., and Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Black Hills folio (No. 219) (in press).

[2] Irving, J. D., Economic resources of the northern Black Hills, with contributions by S. F. Emmons and T. A. Jaggar, jr.: U. S. Geol. Survey Prof. Paper 26, 1904.

[3] Paige, Sidney, Pre-Cambrian structure of the northern Black Hills, S. Dak., and its bearing on the origin of the Homestake ore body: Geol. Soc. America Bull, vol. 24, pp. 293–300, 1913.

that at some future date a more detailed account of this mine, perhaps the greatest gold mine in the world, may be published.

I wish to acknowledge the courtesy of the engineering staff and the substantial assistance rendered in the work by Messrs. L. B. Wright and Joseph Hosted, geologists for the company. After the completion of my underground examination of six weeks in 1920 Mr. Wright and Mr. Hosted completed the detailed mapping of the mine. This work extended over a period of two years. It was possible, therefore, to check my generalized maps with their detailed maps, and it has been a pleasure to acknowledge their cooperation by attaching their names to the mine and surface maps published in this report.

GEOGRAPHY

The Homestake mine is at Lead (pronounced leed), in western South Dakota, in the northern Black Hills. The "hills" embrace an oval area 125 miles long and 60 miles wide, with the longer dimension trending nearly northwest. They rise several thousand feet above the plains. Abundant rainfall, forests, "parks," and streams make the Black Hills an oasis in this semiarid region. They are carved from a dome-shaped uplift of the earth's crust and consist largely of rocks which are older than those that form the surface of the Great Plains. They rise abruptly from the plains, although the flanking ridges are of moderate height. The salient features are the encircling Hogback Ridge, which constitutes the outer rim of the hills; next the Red Valley, a depression that extends completely around the uplift; next a limestone plateau with infacing escarpment; and finally a central area of high ridges culminating in the precipitous crags of Harney Peak, whose crest reaches an altitude of 7,216 feet. Two branches of Cheyenne River nearly surround the hills and receive many tributaries from them.

Because much of the area consists of high forested ridges not well adapted to agriculture the Black Hills support only a small population. The principal stimulus to settlement has been mining, and this industry has built up the neighboring cities of Lead and Deadwood, the former with a population of 5,013 and the latter with 2,403, according to the census of 1920. Most of the mining is nearer to Lead than to Deadwood, and the large Homestake mine is in the city of Lead. Farther south Custer, a village of 595 persons, and Hill City, with 308, are sustained mainly by lumber and ranching interests in the surrounding country, though some mining has been carried on for years. There are many small farms in the numerous "parks" among the hills.

The plains country adjoining the Black Hills is largely occupied by ranches, most of which are devoted to cattle raising. There are several near-by towns and small villages. Rapid City, with a population of 5,777, is the seat of Pennington County and a growing railroad center. Here is the State School of Mines, and near by is the Rapid City Indian School. Sturgis, with a population of 1,250, is the trading center for an extensive ranch country but is partly sustained by the United States Army garrison at Fort Meade, 2 miles east of the town. Spearfish, with a population of 1,254, is the largest town on the north side of the hills. Whitewood, Hermosa, and Fairburn are smaller places.

The Black Hills and the adjoining country are traversed by several lines of railroad. The Chicago, Burlington & Quincy Railroad passes from south to north through the center of the hills to Deadwood and Lead and has a branch to Spearfish. The Chicago & Northwestern Railway extends along the east side of the hills, has a terminus at Lead, and a connecting line from Pierre to Rapid City. A branch of the Chicago, Milwaukee & St. Paul Railway also reaches the hills at Rapid City. Several smaller railroads run through parts of the hills.

GEOLOGY

BROAD RELATIONS

Although the present report is concerned largely with geologic events that occurred in pre-Cambrian time, a very brief outline of the broader features of geologic structure of the Black Hills is of interest, particularly because intrusions of porphyry in Tertiary time have disturbed the structure of the pre-Cambrian beds and, it is believed, have supplied some gold to the pre-Cambrian ore deposit.

The Black Hills uplift is an irregular dome-shaped anticline with its longer dimension trending nearly northwest. The hills, which are surrounded by a wide expanse of almost horizontal beds, are formed of a nucleus of Algonkian crystalline rocks around which there is upturned a nearly complete sequence of sedimentary formations ranging in age from Upper Cambrian to latest Cretaceous, all dipping away from the central mass of ancient rocks. There are also in the hills extensive overlaps of the Tertiary deposits that form much of the adjoining plain. The region affords most excellent opportunities for the study of stratigraphic relations and variations. Many of the rocks are hard, and in such rocks the streams flowing out of the central mountain area have cut canyons and gorges in the walls of which the formations are extensively exhibited. The structure along the sides of the uplift is that of a monocline dipping toward the plains. The oldest Paleozoic sedimentary rocks constitute the escarpment facing the crystalline-rock area, and each stratum passes beneath a younger one in regular succession outward toward the margin of the uplift. The Paleozoic and Mesozoic sedimentary formations consist of a series of thick sheets of sandstone, limestone, and shale, which are all essentially conformable in attitude. The overlapping Tertiary deposits extend across the edges of these older rocks. The stratigraphy presents many points of similarity to that of the Rocky Mountains in Colorado and Wyoming but shows numerous distinctive local features.[4]

Tertiary igneous rocks are abundant in the northern part of the Black Hills. They occur as a series of separate intrusive masses extending northwestward across the northern part of the structural dome from a point near Bear Butte, on the east, to Missouri Buttes, on the west, a distance of about 65 miles. At several places there are small areas of lava and volcanic breccia.

Within this area streams have cut deeply into the Paleozoic and pre-Cambrian rocks, and the structural relations of the intrusive masses are unusually well displayed. The shapes of these masses have clearly been influenced by the attitude of the rock beds they have invaded. Thus the intrusions within nearly vertical pre-Cambrian schist have the form of dikes and stocks. On the other hand, the many sheets and irregular laccoliths that cut the overlying Paleozoic sediments and are exposed in all stages of denudation conform more or less perfectly to the bedding planes of the sediments or have caused these relatively flexible rocks to rise as domes.

Most of the intrusions lie within an oval area about 20 miles long, which trends nearly southeast and extends from Spearfish Canyon to a point about 5 miles east of Elk Creek post office. The western part of the area, about 10 miles in greatest breadth, surrounds the city of Lead. Outlying intrusive masses on the northwest are Crow Peak and Citadel Rock; Custer Peak, on the south, and Bear Butte, on the northeast, also stand more or less isolated.

The roughly oval shape of this intrusive area is characteristic of the other intrusive area lying to the west. These intrusive masses are localized in areas where sedimentary strata have been forced up

[4] For a detailed account of the geology of the Black Hills, see Darton, N. H., Geology and underground water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, 433 pp., 1905: Preliminary description of the geology and water resources of the southern half of the Black Hills and adjoining regions in South Dakota and Wyoming: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 4, pp. 489–599, 1901; Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: U. S. Geol. Survey Prof. Paper 65, 1909; Jaggar, T. A., Jr., Laccoliths of the Black Hills: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 3, pp. 163–303, 1901; Darton, N. H., and others, U. S. Geol. Survey Geol. Atlas, Oelrichs, Newcastle, Edgemont, Sundance, Aladdin, Devils Tower, and Belle Fourche folios (Nos. 85, 107, 108, 127, 128, 150, 164), 1902–1907; Paige, Sidney, and Darton, N. H., U. S. Geol. Survey Geol. Atlas, Black Hills folio (No. 219) (in press).

by igneous rock—that is, the areas containing intrusive masses are coextensive with the areas of pronounced local deformation.

Although these igneous rocks exhibit considerable diversity in color and texture, and although the rhyolite, quartz monzonite, monzonite, phonolite, and grorudite families are represented, all are chemically related. They were intruded about the same time geologically, from a common magma.

PRE-CAMBRIAN GEOLOGY OF THE BLACK HILLS

The nature of the Homestake ore body will be more clearly understood if the general character and structure of the pre-Cambrian rocks of the Black Hills as a whole are briefly described.

PREVIOUS WORK [5]

The first published mention of the existence of pre-Cambrian rocks in the Black Hills appeared in 1859.[6] In this paper F. V. Hayden recognized the pre-Cambrian age of the granite and metamorphic rocks and correlated them with those of the Lake Superior region. Again in 1862, 1863, and 1872 he briefly described their nature. Winchell [7] in 1875 also described a series of mica slates and mica schists below the "Primordial sandstones." The first report that treated in detail of these rocks, however, was that of Newton and Jenney,[8] published in 1880. This report, in view of the short time spent in exploration and the breadth of the field covered, is remarkable for its thoroughness, accuracy, and generally scientific viewpoint. Though some of the conclusions of these authors regarding the pre-Cambrian rocks have been modified by subsequent work, it is evident that they clearly understood the nature of these rocks. Writing at a time when speculation regarding the nature of granite was rife, Newton set forth concisely the facts that established the intrusive character of the granite in the Black Hills, though a later observer, W. O. Crosby,[9] disputed his conclusion.

Newton did not recognize the complex folding which had affected the rocks; but this is not surprising, for the dips are for the most part steep, many of the strata are monotonously alike, and it is only by detailed work that the folding can be made out. The basis for

[5] For summary of the literature covering the Algonkian rocks of the Black Hills, see Van Hise, C. R., and Leith, C. K., Pre-Cambrian geology of North America: U. S. Geol. Survey Bull. 360, pp. 727–733, 1909.

[6] Hayden, F. V., Acad. Nat. Sci. Philadelphia Proc., vol. 10, pp. 139–158, 1859.

[7] Winchell, N. H., Geological report on the Black Hills of Dakota: Chief Eng. U. S. Army Rept. for 1874, vol. 2, pt. 2, pp. 1131–1172.

[8] Newton, Henry, and Jenney, W. P., Report on the geology and resources of the Black Hills of Dakota, with atlas, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[9] Crosby, W. O., Geology of the Black Hills of Dakota: Boston Soc. Nat. Hist. Proc., vol. 23, pp. 488–517; vol. 24, p. 11, 1888.

his division of the rocks into an older and a younger series, however, is not clear, even if considered on purely lithologic grounds, and it is interesting to note that the results of petrographic work by J. H. Caswell for the same report did not support the division. Caswell found the rocks of the "two series" essentially alike.

A number of other workers supported Newton's dual division of younger slates and older schists, but the correctness of this view was questioned when Van Hise[10] visited the field in 1890. Van Hise recognized the folded attitude of the rocks, the cleavage induced by the folding, and the secondary foliation produced by the granitic intrusion. He found no basis for a division into an older and a younger series. He went too far, however, in his assertion that the prominent structural features previously taken as bedding are secondary and in his restriction of the schists to the vicinity of the granite and to the northern hills, where late porphyries have invaded the rocks.

Later workers, particularly Irving and Jaggar, have described the pre-Cambrian rocks and the economic resources of the northern hills, though they undertook no systematic areal mapping of the pre-Cambrian formations.[11]

BROAD RELATIONS OF THE PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks are exposed in an oval area about 60 miles long and 25 miles wide at the widest part, trending northwest from a point 2 miles south of Pringle, in Custer County, to a point 3 miles beyond Lead, in Lawrence County. The area is the highest in the Black Hills dome, and in most of it the Paleozoic and younger rocks have been completely worn away. In its extreme northern part, however, near Lead and Deadwood, there remain many small inliers of Paleozoic strata, and the Deadwood-Lead pre-Cambrian area is separated from the southern pre-Cambrian area by a narrow neck of Cambrian sediments and late intrusive porphyry.

CHARACTER OF THE PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks of the Black Hills may be divided into three general classes—metamorphosed sediments, metamorphosed diorite or gabbro, and essentially unmetamorphosed granite and pegmatite. The metamorphosed sedimentary rocks form the bulk

[10] Van Hise, C. R., The pre-Cambrian rocks of the Black Hills: Geol. Soc. America Bull., vol. 1, pp. 203, 244, 1890.

[11] Irving, J. D., A contribution to the geology of the northern Black Hills: New York Acad. Sci. Annals, vol. 12, pt. 9, pp. 187–340, 1899. Jaggar, T. A., jr., The laccoliths of the Black Hills: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 3, pp. 171–303, 1901. Irving, J. D., Economic resources of the northern Black Hills—pt. 1, General geology, by T. A. Jaggar, jr.: U. S. Geol. Survey Prof. Paper 26, pp. 13–41, with geologic map, 1904.

of the assemblage. They comprise the metamorphic equivalents of common types of sedimentary strata—conglomerate, grit, sandstone, shale, and limestone. The diorite and gabbro are represented by amphibolite derived from intrusive stocks and sheets. The granite is locally gneissoid.

Inasmuch as no general map of the Black Hills accompanies this report, the description that follows will take no account of localities and the distribution of the sediments will be considered only in the vicinity of the Homestake mine. The main purpose of this description is to emphasize the originally sedimentary character of the bulk of the pre-Cambrian schists.

METAMORPHOSED SEDIMENTARY ROCKS

Conglomerate occurs at various horizons in the series and grades upward, downward, and along the strike into sediments of finer texture (arkosic grit). These conglomerates have been deposited as lenses or channel fillings of various lengths and thicknesses and contain waterworn pebbles and boulders, some of which are a foot or more in diameter. The pebbles are predominantly white quartz, but blue quartzite, banded quartz and iron oxide, contorted schist, black slate, and cross-bedded siliceous schist or sandstone are also represented among them. The matrix is mainly quartzitic but contains much feldspar, mica, and chlorite. The conglomerate where fresh has a distinctly greenish cast, owing to its micaceous and chloritic minerals. The beds have been compressed and distorted by crushing, flowage, and recrystallization, and the pebbles and boulders have been squeezed into lenticular forms, whose longest diameter parallels the dip of the beds. The feldspathic and clayey material within the matrix has been converted in great part into the micaceous minerals sericite and chlorite.

Coarse arkosic grit is especially abundant and grades into conglomerate on the one hand but into finer-grained sediments on the other. It was composed originally of various proportions of feldspar and quartz. The feldspar is now to a considerable degree altered to sericite and quartz, and small quantities of chlorite have developed. The chlorite proves that iron and magnesia were present in the original sediment. That the quartz grains have been mashed is plainly discernible with the microscope. They are roughly lenticular. Much of the débris in this coarse arkose is angular and suggests somewhat rapid accumulation. The sericite, which is abundant, determines the plane of foliation of the rock and may be seen in places wrapped around the more rigid grains of feldspar and quartz. These arkosic rocks have when fresh a distinctly greenish hue, due to abundant chlorite, but weathered surfaces are red, yellow, or light brown. In color they contrast sharply with the dark slate and graywacke described below. The arkose grades imperceptibly into finer-grained quartzitic schist, which also is characterized by light colors on weathered surfaces.

Large areas are underlain by graywacke, a metamorphic feldspathic sandstone, which grades on the one hand into nearly pure quartzite and on the other into slate or schist. Although many of these rocks have medium-grained texture they are sufficiently resistant to erosion to form rugged hills. The graywacke comprises rocks of many textural gradations, from those in which the individual grains are plainly visible to those in which the grains can hardly be seen. They merge therefore on the one hand into grit and on the other into slate and schist. The beds change their texture along the strike as well as across the bedding.

Besides the massive quartzite associated with the graywacke there are many minor beds of quartzite within the schist series. In general individual beds may divide along the strike and be replaced by two or more beds, or they may either thicken or thin. Because of such changes and because of the squeezing and tearing to which the beds have been subjected their outcrops are neither regular nor continuous. Nevertheless they are sufficiently continuous to prove of great importance in unraveling the intricate structure of the rocks involved.

All the quartzites are lithologically very much alike. They are dark gray to blue-black and of vitreous luster when freshly fractured. Almost everywhere they contain vein quartz in networks of veins and veinlets and in great or small masses. It is noteworthy that the deposition of secondary silica by which these veins were formed was more extensive in quartzite beds than elsewhere. This may be due in part to the solution and redeposition during metamorphism of silica originally present in the quartzite.

Under the microscope the quartzite is seen to be made up of quartz, a little sericite, and an appreciable amount of carbonaceous matter. The carbonaceous or graphitic matter is arranged in lens-like films, surrounding aggregates of interlocking quartz grains, each aggregate representing a crushed and recrystallized quartz fragment. This graphitic material gives the rock its dark color.

The slate and schist form a group of rocks characterized by generally good cleavage and fine grain. Their colors range through light hues of gray or green, darker gray, light and dark brown, to black. The very fine grained varieties may have a silky luster and wavy cleavage surfaces. In many places a perfect cleavage cutting across bedding planes may be noted, although the cleavage is generally parallel to the bedding. Where soft rocks are folded and crinkled, the cleavage will cross the bedding planes on and near the axial plane of each fold. These rocks consist of quartz, feldspar, sericite, biotite, chlorite, carbonate, garnet, and iron oxide. Staurolite and tourmaline occur in places but are not abundant. Differences in original composition and texture and in the degree of metamorphism to which the beds have been subjected account for the various kinds of schist and slate. Where particular beds are of coarse texture and where metamorphism has not been thorough, signs of clastic origin are plainly visible. Individual grains of quartz and feldspar remain unbroken, set in a matrix of sericite, chlorite, feldspar, and quartz, containing scattered grains of iron oxide. Such unbroken grains on further deformation have been crushed, recrystallized, and drawn out into lenslike forms, and ultimately they can be recognized only by the carbonaceous matter that surrounds them.

Biotite-sericite-quartz-feldspar schists are common rocks. The biotite may be very scanty or very abundant. The composition of the rock may vary noticeably from bed to bed within a few feet or may remain the same through a considerable thickness. In many specimens the mashed recrystallized grains are plainly visible. In others the relatively large fragments are lacking, the original bed having been more even textured. In places biotite schist shows with striking clearness the clastic nature of the bed from which it was derived. The grains of feldspar and quartz may be seen in various stages of crushing, and the biotite is alined with the schistosity of the rock and is entirely secondary. Here and there biotite has been developed after deformation had ceased, as is evident where the long axis of the biotite crystal crosses the direction of the schistosity, also where the biotite crystals are spongelike and poikilitically inclose the other constituents of the rock. Garnets, mostly small but some as much as a quarter of an inch in diameter, are present in many biotite schists. Few of them are deformed. Apparently they have developed later than the schistosity of the rock and have replaced the biotite and quartz or feldspars. Some are solid crystals with sharp crystal faces and others are spongelike crystals which poikilitically inclose the remaining minerals. Tourmaline is present in some of the schists and is usually a contact-metamorphic mineral, for in the granite it is abundant.

Carbonate rocks, though forming but a very small part of the pre-Cambrian assemblage, are found at many horizons throughout it and are important both stratigraphically and economically. The carbonate rocks in places are fine grained, fairly pure, and generally light colored, showing various hues of yellow, brownish white, or blue. By the addition of quartz or aluminous material they grade into the fine-grained arkosic schist. Where originally mixed with fine aluminous sediment they have become sericite phyllite; by the admixture of sand they grade rather abruptly into siliceous schist. On weathered surfaces these rocks usually assume darker hues of brown and yellow. In many places, too, fine ridges of siliceous material stand out on such surfaces. These ridges are especially useful as a means of recognizing the rocks in the field. In general the carbonate rocks are massive rather than schistose, so that the effect of metamorphism on them is less conspicuous than on the more sandy beds. Locally, however, impurities that are present in layers have altered to sericite and chlorite, and the rock cleaves readily along the planes of these layers. The carbonate beds differ in thickness and in persistence along the strike.

At many places the schist derived from impure calcareous or dolomitic sediments, which contained clay and sand, carbonaceous matter, and iron, bears little resemblance to the original sedimentary rock from which it was derived, and only a practiced eye will detect its nature. Where carbonaceous matter and silica were the principal impurities, the schist is graphitic, is dark blue to black, and may easily be mistaken for a graphitic slate, but on weathered surfaces the fine ridges of silica that stand out in relief give to the rock a characteristic appearance.

Banded quartz-hematite beds are developed at several places. These beds grade along the strike and across it into the other rocks of the series. They are not confined to a single horizon but occur either below, above, or partly associated with the carbonate rocks. The beds consist of black specular hematite and crystalline quartz in alternating layers a fraction of an inch to a few inches in thickness. In many places abundant chlorite and green mica are also present. The hematite is in places interlayered with carbonate and may be crumpled and broken. Indeed, it is difficult or impossible to decide in some places whether a conglomerate or a breccia is present. Many of these rocks are certainly breccias. The perfect banding has been destroyed, the quartz layers are discontinuous, and in cross section the rock presents the appearance of a flattened-pebble conglomerate. It is believed, however, that this coarse clastic appearance of the beds is generally due to brecciation, the stiff quartz layers having parted under the stress of close folding and having been drawn out into lenslike bodies. This is certainly true at some places where the brecciation of the rock has not been masked by sufficient pressure and folding to give the fragments that rounded form so deceptive in other places. The broken pieces may be seen only a short distance removed from one another and still angular enough and of such shape as to prove their former continuity. The field relations of these rocks indicate that they are sediments. The iron may well have been present originally as ferrous carbonate.

IGNEOUS ROCKS

The schist is invaded by pre-Cambrian igneous rocks of two periods—an earlier group of dioritic intrusives, now highly metamorphosed to amphibolite, and a later group of unmetamorphosed granite and pegmatite.

AMPHIBOLITE

The amphibolite is a metamorphic rock derived from igneous rocks of diorite-gabbro composition. It is of various hues from light gray to deep green or nearly black and is for the most part, especially in large intrusions, of massive appearance. At the borders of the amphibolite masses, however, the rock is schistose and in many thin sills closely resembles chlorite or biotite schist of sedimentary derivation. The amphibolite ranges in texture from medium to fine grained, usually according to the coarseness of the original igneous rock. The coarser-grained varieties show clearly their igneous character: hornblende and feldspar are readily observed with the naked eye, and the rock is easily recognized as a diorite. The finer-grained varieties, if massive, are also in appearance characteristically igneous rocks, as for example the metadiabases; but these rocks where very schistose resemble metamorphic sedimentary schist.

The amphibolite is composed of amphibole, feldspar, quartz, chlorite, zoisite, epidote, calcite, and a little apatite. Pyrite may be present. All these minerals, except some of the feldspar and perhaps some of the hornblende, are secondary, are products of dynamic metamorphism, and are derived in the main from the breaking down of feldspar, augite, and hornblende of the original dioritic rocks.

In none of the rocks observed was augite recognized with certainty. Metamorphism has everywhere proceeded too far to leave unaltered any of this very common constitutent of diorite and diabase. Except for this break in the chain, all degrees of alteration may be observed, from rocks unquestionably igneous to those in which no igneous texture remains.

The essential process in the metamorphism that produced the amphibolite consisted in the combined mechanical and chemical breaking down of the original minerals and their replacement by metamorphic minerals. The borders or cleavage planes of feldspar were first attacked by amphibole or chlorite, or zoisite and chlorite may have ultimately developed at a number of points within the crystal, completely filling the space once occupied by the feldspar. Hornblende penetrated feldspar crystals and replaced them by tufts of needle-shaped crystals springing from the border of the hornblende, and zoisite appeared at the same stage within the feldspar mass. An endless variety of patterns was formed. Zoisite may have developed in dense aggregates of small grains replacing feldspar, or idiomorphic crystals of epidote may have been formed. Granulation of feldspar may be observed in many places, and where the rock exhibits considerable schistosity zoisite may be arranged in flowing lines, or amphibole may be the dominant mineral oriented with the schistosity. In some of the rocks hornblende is entirely lacking and chlorite takes its place as the dominant metamorphic mineral.

When the folding of the sedimentary beds and the very steep dips that prevail in them are taken into account, it becomes evident that the parts of the amphibolite now exposed are but cross sections of the masses. Only two suppositions are possible as to the origin of these amphibolite masses—either that they represent lava flows or that they represent intrusive sill-like masses and dikes. The weight of evidence, both structural and petrographic, supports the second supposition. It is possible to account for certain forked masses, not mentioned before, as produced by combined surface and subaqueous lava flows, but the petrographic character of the rock that takes this form is opposed to such an origin. The undoubted crosscutting masses of dioritic and diabasic character, in no important way different from narrow sills, point to an intrusive origin, and the presence of many minor intercalated sills favors this view. It is believed, therefore, that the amphibolites are the metamorphosed equivalents of basic intrusive rocks injected into the sedimentary series.

GRANITE AND PEGMATITE

Granitic intrusives occur principally in the southern part of the pre-Cambrian area, but there is a small area of gneissoid granite crossing meridian 103° 30′ 3 miles north of Nemo. Few dikes are found north of the latitude of Hill City. Another mass about 2 miles long on the western border of the area extends about the same distance to the north.

The largest mass of granite unmixed with schist lies south of Hill City; it is roughly circular and about 10 miles in diameter. East, south, southeast, and southwest of it to the Paleozoic boundaries much of the country is cut by numberless masses and dikes of granite, both large and small.

Surrounding the principal granite mass is a zone of varying width in which the schistosity follows the contact and along which many parallel dikes have been injected. The dikes range in width from a few feet to several hundred feet and in places extend without interruption for a mile or more. Elsewhere, notably south of Sylvan Lake, there are zones of intricate intrusion and impregnation; blocks of schist may be seen in every stage of change from those clearly recognized as fragments to those having essentially the nature of an igneous rock. Where the contact is of this nature it is not possible to draw an accurate boundary line between schist and granite.

The granite is a muscovite granite carrying an unusual amount of tourmaline. Of the feldspars microcline, orthoclase, albite, and oligoclase may be present. Microcline is the most abundant. Muscovite is almost always present, and biotite, though not abundant, appears in some places. Tourmaline occurs in crystals and grains and may be either blue or brown in thin section. Apatite, magnetite, zircon, and titanite are common accessory minerals, and garnets also occur.

In the coarse varieties microcline is perthitically developed with albite and intergrown graphically with quartz. The crystals of such microcline are large, commonly several inches in length. Albite, oligoclase, or orthoclase may occur as individual crystals. Some of the pegmatite dikes carry a great variety of minerals, many of them rare.

The finer-grained varieties of the granite are granular rocks of similar mineral composition in which quartz, microcline, and muscovite are almost always prominent. A little biotite may be intergrown with muscovite.

Much of the granite is so extremely coarse that the term pegmatite fits the rock almost as well as granite. This is especially true of much of the larger mass surrounding Harney Peak, where except at the borders there is very little admixture of schist. It applies precisely to most of the dikes that cut the schist at numberless places. There are masses, however, particularly in the complexly intruded and broken terranes east and southeast of Harney Peak, that are more normal, being medium to coarse granite, with a few masses of finer grain.

Perhaps the most striking mineralogic characteristic of the granite is the almost invariable presence of more or less tourmaline. This mineral is found in both coarse and fine grained varieties and very abundantly in the pegmatite. In many places it may be counted among the major constituents of the rock. It occurs as fine grains or as slender prismatic crystals in the finer-grained granite, with quartz and feldspar, and may be the only dark constituent of the rock. A little biotite or muscovite or both may be present in other varieties, or the tourmaline may be absent, and only biotite or muscovite may accompany the quartz and feldspar.

The coarse-grained mass around Harney Peak is composed of quartz, feldspar, tourmaline, and muscovite. Its texture is notably irregular. Feldspar is micrographically intergrown with quartz, and individual crystals of the feldspar may attain large size yet be literally filled with quartz. Irregular masses of this quartz are also abundant but sporadically distributed through the rock. Tourmaline or muscovite or both may occur in groups of large crystals or may be disseminated throughout the rock.

A rude layering, visible only on a large scale and due in a broad way to the arrangement of the minerals of the rock, may be observed in this central mass. It dips outward with the dip of the schist and flattens as it approaches the summit of the mass. It is probably connected with pressure exerted during intrusion.

STRUCTURAL GEOLOGY

Broadly viewed, the pre-Cambrian rocks of the Black Hills comprise a thick series of slate and schist, for the most part monotonously alike, which strike northwest and generally have steep dips to the east, except in the extreme southwestern part of the hills. On the south intrusions of granite break through the strata, and around the principal mass, which includes Harney Peak, a schistosity parallel with the granite contact is developed.

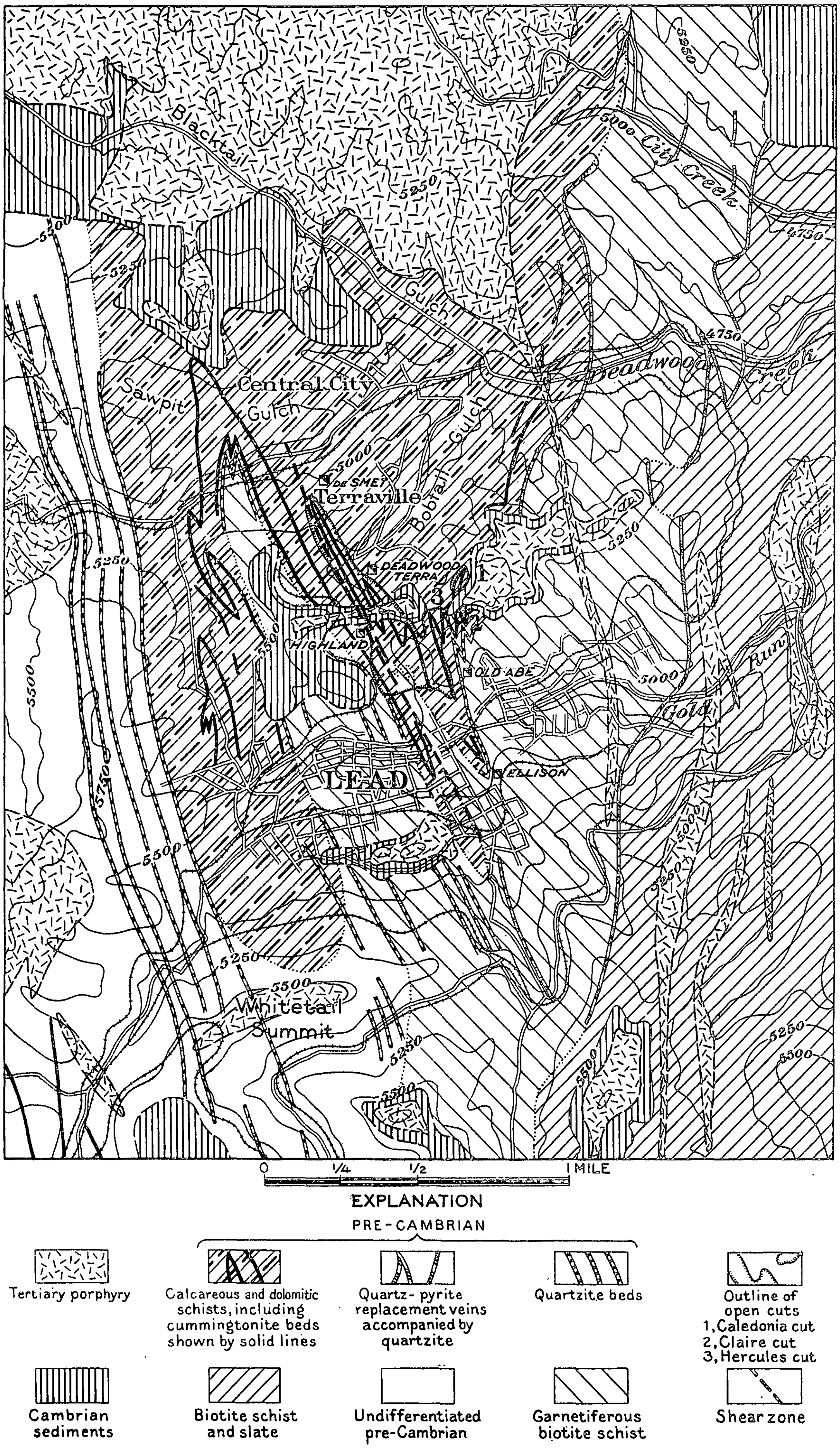
A closer study, however, shows that the schistosity is for the most part parallel to the bedding; that the series is compressed into a number of great folds, upon which are innumerable minor isoclinal folds; and, finally, that a sufficient number of individual beds can be traced to establish the position and nature of the greater axes of folding and to reveal the presence of important faults.[12] The structure in the vicinity of the Homestake mine is described on pages 25–42.

PRE-CAMBRIAN GEOLOGY IN THE VICINITY OF LEAD

STRATIGRAPHY

It is possible to subdivide the pre-Cambrian metamorphic sedimentary rocks in the vicinity of the Homestake mine into lithologic groups and by tracing certain beds to decipher the major folds in which they are involved. The boundaries of these subdivisions are drawn on Plate I. From east to west, presumably in descending order, the schists comprise the following groups: (1) Biotite schist and slate, characteristically exposed in the region around Deadwood and farther west. (Near the base of this group there are bodies of amphibolite schist derived from basic intrusions. These are not shown on the map.) (2) A thin layer of quartzite accompanying graphitic slate and locally strongly pyritized. This bed has been

[12] See Paige, Sidney, and Darton, N. H., U. S. Geol. Survey Geol. Atlas, Black Hills folio (No. 219) (in press).



GEOLOGIC MAP OF THE VICINITY OF LEAD, S. DAK.

By Sidney Paige, L. B. Wright, and Joseph Hosted traced with minor interruptions from the Cambrian contact on the north to a point near Kirk, beyond which I did not determine its position with assurance, but it has been further traced by Wright and Hosted and appears to swing westward around the nose of the Lead anticline. (3) A group of garnetiferous and biotitic schists lying directly beneath this quartzite. (4) A number of thin layers of quartzite interbedded with slate (75 feet in thickness), which have been followed, with interruptions by porphyry and Cambrian cover, from the basal Cambrian contact on the north into the Homestake mine, where they are involved in folds with which the ore body is associated. (5) A series of argillaceous slate, dolomitic and calcareous slate, and schist, directly beneath these thin quartzites. Within this dolomitic series and not far beneath the overlying quartzites are a number of highly metamorphosed beds carrying varying amounts of the amphibole cummingtonite and in places also garnet. Two of these beds (separated by 150 feet of slate) have been followed with interruptions from Bobtail Gulch to and into the Homestake ore body, of which they form a very important part.

PETROGRAPHY

The general petrographic features of these pre-Cambrian rocks have already been described somewhat fully. Here, therefore, I will mention only briefly those units that are not important as ore carriers but will describe in detail the carbonate series, which carries the bulk of the Homestake ore.

BARREN ROCKS

1. The biotite schist and slate, which are abundant in the Black Hills, are composed of quartz, feldspar, biotite, and sericite in proportions that vary like those of sand and clay in unmetamorphosed sedimentary rock. The composition may vary noticeably from bed to bed within a few feet or may remain essentially constant through a considerable stratigraphic thickness. With a microscope the grains of quartz and feldspar may be seen in various stages of crushing, and the biotite is alined with the schistosity of the rock. The essential thing to note here about these rocks is their generally siliceous character. They are not rocks particularly susceptible to replacement by ore-bearing solutions except along open fractures.

2. The quartzite and graphitic slate are grouped together because of their prominence at the surface. They are very useful in deciphering structure. The quartzite, though thin, is persistent and is associated in all its outcrops with a black graphitic pyritized slate. Surficial oxidation of the pyrite has produced a prominent outcrop "comb" of red iron oxide and silica known locally as the "iron

dike." Pyrite is so abundant in some places that it was mined in the early days, notably at the Montezuma & Whizzers property, in Deadwood Gulch, and used by the smelters. In places a slate lies above the quartzite, in places below. In still other places the quartzite is represented by two beds. This irregularity is not surprising, however, for beds of sandstone at many places are conspicuous for their variation along the strike. The quartzite and graphitic slate are important in this discussion wholly because of their structural significance. They occur nowhere in the mine proper.

3. The garnetiferous schist, directly beneath this thin quartzite and black slate, is in all its broad essentials similar to the biotite schist overlying the quartzite and black slate, but it generally carries varying amount of garnets, which are mostly small but may be very abundant. Apparently the garnets were developed at a slightly later stage than the schistosity of the rocks, and they appear to have replaced biotite, quartz, and feldspar. Some are solid crystals with sharply defined faces; others are spongelike crystals that inclose the other minerals. The composition of the garnets indicates a change of sedimentation in the direction of increased iron, magnesia, and calcium carbonate, which become so conspicuous in the underlying rocks.

4. The narrow band of alternating thin quartzites and slates, about 75 to 100 feet thick, presents no unusual petrographic features but is important structurally, as the group can be traced on the surface and recognized in the Homestake mine. These quartzites overlie the ore at many places, though in other places apparently the ore horizon stops somewhat below them. The beds, as might be expected from their origin, change from place to place in thickness and relative position with reference to the included slate bands and have been thickened, thinned, and broken by folding. Nevertheless, as a group they are persistent and can be used to aid structural interpretations where all other evidences of the intricacies of folding are lacking.

ORE-BEARING ROCKS

5. The calcareous and dolomitic schists are the rocks that contain the ore, and the recognition of the notable amount of carbonate in these rocks and the nature of the structure which the beds display is the fundamental basis of an adequate understanding of the Homestake ore body. Therefore, a more detailed description of their mineralogy follows.

The carbonate series includes many varieties of schist in which, besides varying amounts of iron, magnesium, and calcium carbonate, there occur biotite mica, sericite mica, phlogopite (green mica), chlorite, amphibole, garnet, and quartz.

In the railroad cut opposite the mouth of Blacktail Gulch, on Deadwood Creek, a fairly pure band of the calcareous rock crops out, and there are many places in Bobtail Gulch (the small gulch on which Terraville is built), as well as in Deadwood Gulch in the vicinity of Central City, where the calcareous beds, more or less impure, may be observed.

A highly metamorphic bed that crops out on Deadwood Creek a short distance below the mouth of Blacktail Gulch and can be traced, with interruptions, to the Homestake open cut and thence into the mine is peculiar in that it contains many small flattened lenses and bands of sugar-grained quartz set in a compact matrix of cummingtonite, the iron-magnesium amphibole, and a lime-iron-aluminum garnet. The development of these silicates suggests at once that the bed may be the metamorphic equivalent of a sideritic dolomite and that the quartz may represent residual chert. A second bed similar to this one occurs a short distance lower stratigraphically but can not be traced so far, though in the upper workings of the mine and on some lower levels there are certainly more than one of these beds.

A common variety of this calcareous schist is characterized by chlorite and biotite. This rock exhibits various shades of green and has in places a decidedly micaceous appearance and a moderately well-developed cleavage. On casual inspection it shows little resemblance to limestone, though it may carry as much as 50 per cent of carbonate. A variety noted at a number of places in the northern hills is light grayish green and spotted with red iron oxide. It is a schistose rock composed of quartz and chlorite, throughout which are scattered patches of oxidized ferriferous dolomitic carbonate. There is no possibility of this carbonate being secondary in origin. It is certainly an integral part of the original rock.

An unusually pure carbonate rock, probably a dolomite, occurs in Deadwood Gulch just west of the small mill town of Central City.

As may be plainly seen by consulting the geologic map (Pl. I) the strike of this carbonate series carries it directly into the Homestake mine, and in the following section under "Structure" and in the descriptions of the ore bodies its relations to the ore will be pointed out. Abundant specimens of ore and wall rock were collected and examined with a microscope, and a number were analyzed to prove that the series represented in the ore zone is this carbonate series. A description of some of the types found in the mine follow.

At the extreme north end of the ore body, on the surface, in the De Smet open cut, a remnant of ore remained undisturbed in the trough of a minor synclinal fold. This rock is dark green to black and rather massive and micaceous. With the microscope abundant carbonate can be seen, which on analysis proves to be magnesium and iron carbonate. The percentages of lime, magnesia, iron, and carbon dioxide soluble in acid were determined as follows: CaO, none; MgO, 2.6; Fe_2O_3, 23.9; CO_2, 7.2. From these figures the percentage composition of carbonates was calculated, thus: $CaCO_3$, none; $MgCO_3$, 5.4; $FeCO_3$, 11.6; Fe_2O_3 (as limonite), 16. Manganese carbonate was not present. The carbonate is abundant and, as may be seen in Plate II, *A*, appears as cloudy patches set in a groundmass of quartz and green mica. The border of many of the carbonate patches has altered to a brownish-red mineral, possibly limonite. There is no doubt that this carbonate is an integral and original part of the rock, and that this rock was before metamorphism a dolomitic or sideritic sandstone. This rock is the ore carrier of the De Smet ore body of the Homestake mine.

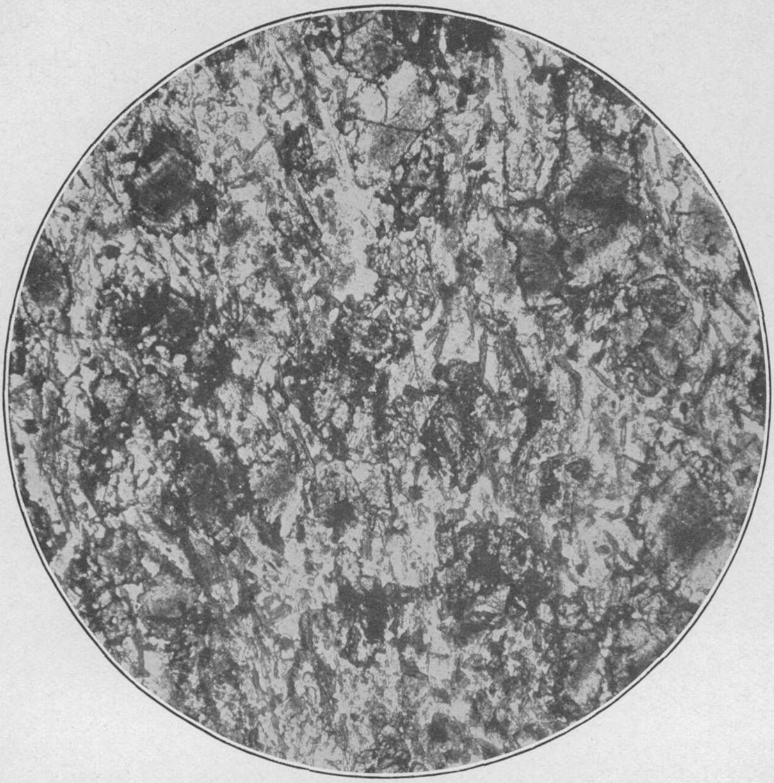
On the 300-foot level at the B. & M. (Old Abe) shaft a bluish banded calcareous schist is made up dominantly of carbonate with abundant chlorite, some mica, some amphibole, and subsidiary quartz. (See Pl. II, *B*.)

An analysis shows the following percentages of carbonates: $CaCO_3$, 5.5; $MgCO_3$, 9.6; $FeCO_3$, 4.7; also Fe_2O_3 (as limonite), 28.3. Here, as in many other specimens to be described, it is clear that the mica and amphibole have replaced carbonate. This rock was originally a dolomitic iron-bearing carbonate rock. This rock is related to the small Old Abe ore body, of which the ledge matter consists of such materials in varying degrees of replacement by amphibole, mica chlorite, and sulphides.

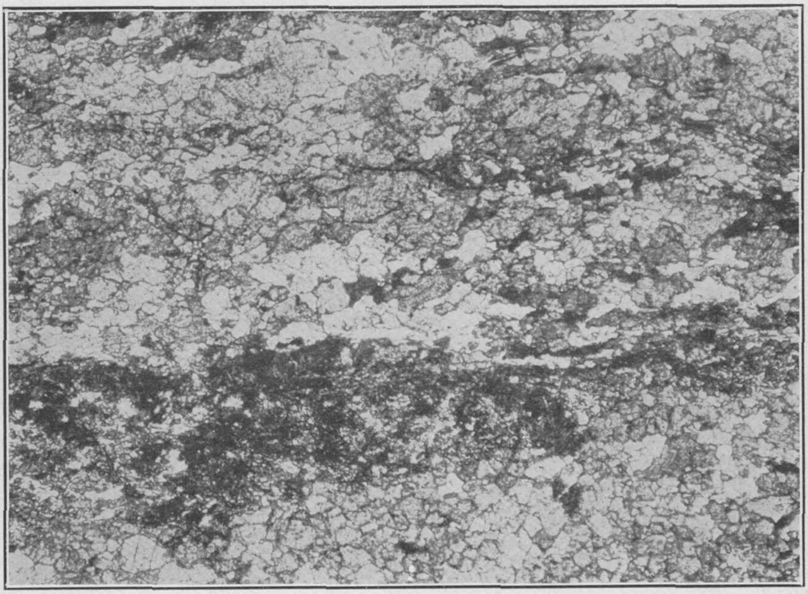
Another specimen collected at the edge of the ore body on the 300-foot level is a siliceous schist but contains layers of carbonate.

Typifying the more highly metamorphic examples of these carbonate rocks is the "80-foot" ledge on the 400-foot level. This stratum is west of the main ore body and west of the footwall shear zone and is not shown on the map, but it is typical of the highly metamorphic strata found also east of the fault. Here there is an abundant development of cummingtonite and green mica, enmeshed in a groundmass of quartz and a subsidiary feldspar. Residual carbonate is seen with the microscope, and Plate III, *A*, illustrates clearly the characteristic fan-shaped development of cummingtonite, the iron-magnesium amphibole. It is significant that in places the carbonate, like this silicate, proves to be quite free of calcium.

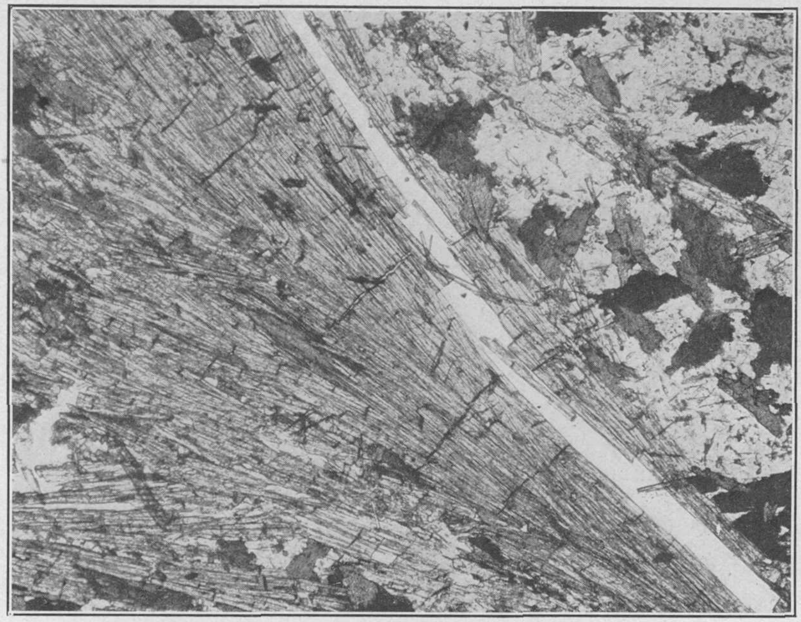
Another specimen, illustrated in Plate III, *B*, from the small Independence ledge on the 300-foot level, shows the growth of cummingtonite even more clearly than the previous specimen. At this locality the Independence ledge is plunging southeastward, as if forming the nose of an anticlinal fold. The specimen was collected



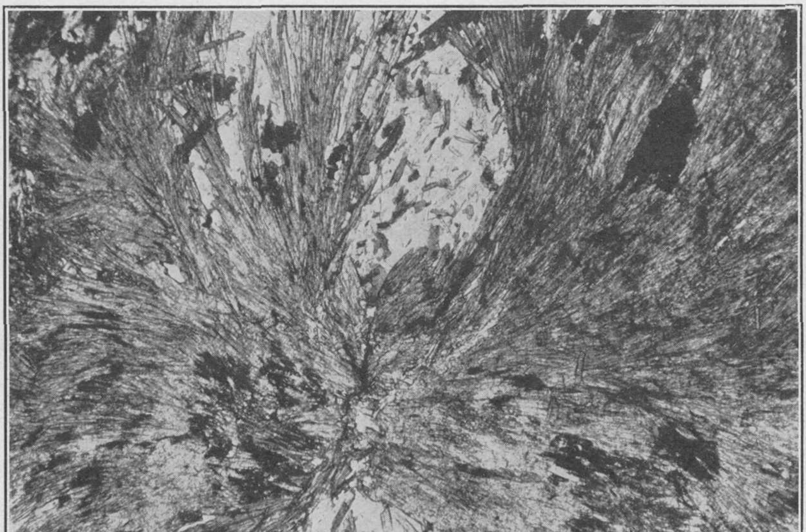
A. CARBONATE ORE FROM NORTH END OF DE SMET CUT ON SURFACE



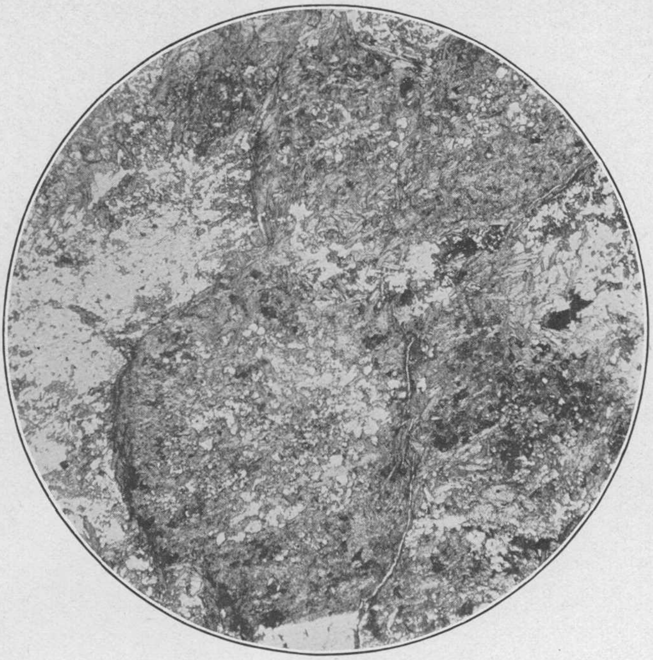
B. DOLOMITIC IRON-BEARING CARBONATE ROCK FROM THE 300-FOOT LEVEL AT B. & M. SHAFTS



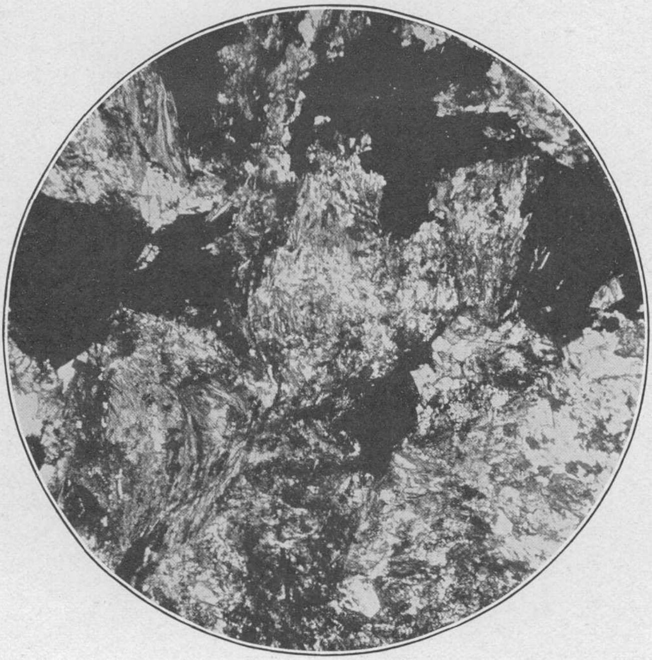
A. HIGHLY METAMORPHIC CARBONATE ROCK FROM THE 400-FOOT LEVEL WEST OF THE MAIN FAULT



B. CUMMINGTONITE ROCK FROM THE INDEPENDENCE LEDGE WEST OF THE FAULT

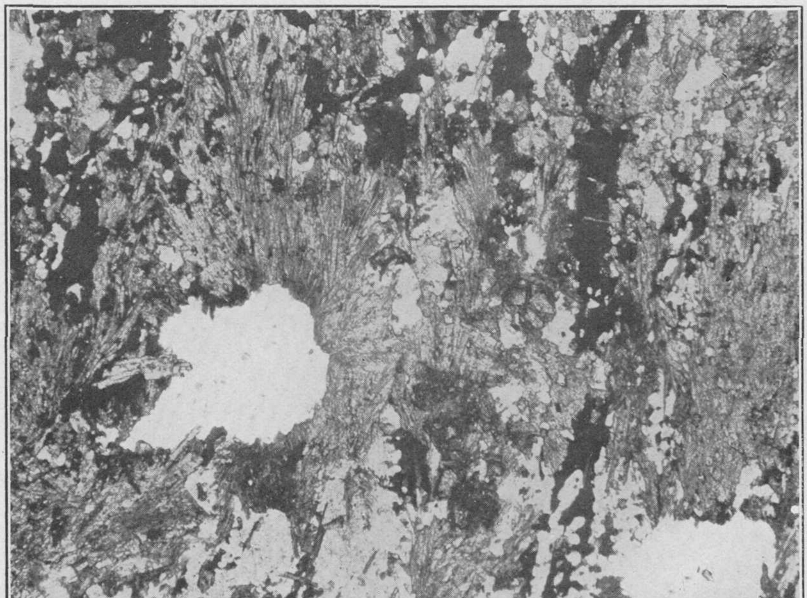


A. CHLORITE SCHIST ASSOCIATED WITH SMALL ORE BODY ON THE 400-FOOT LEVEL NEAR B. & M. SHAFTS



B. ORE FROM THE CALEDONIA ORE BODY ON THE 400-FOOT LEVEL

A. ALMOST COMPLETE REPLACEMENT OF A CARBONATE ROCK BY CUMMINGTONITE, GREEN MICA, BIOTITE, AND CHLORITE

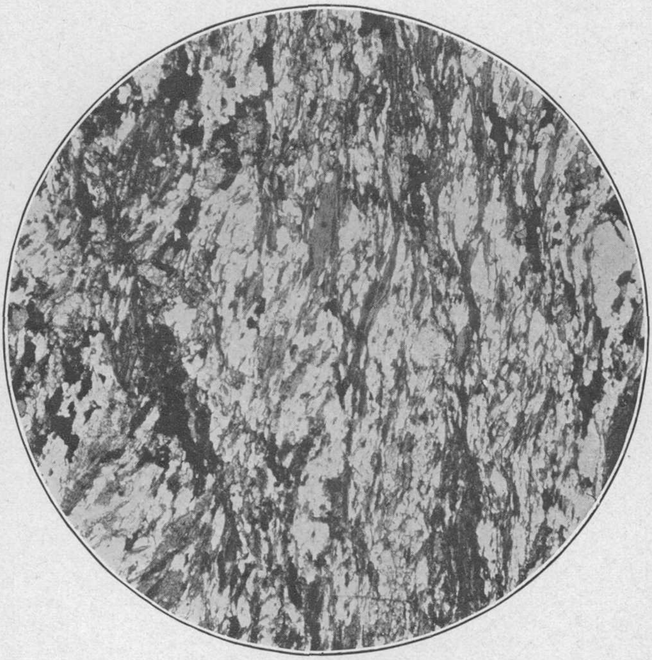


B. BANDED CARBONATE ROCK FROM THE 500-FOOT LEVEL OF THE INCLINE ORE BODY

A. CARBONATE QUARTZ ROCK MAKING UP PART OF THE OLD ABE ORE BODY ON THE 700-FOOT LEVEL

B. CARBONATE BED NEAR THE TERRA SHAFT ON THE 300-FOOT LEVEL

A. SILICATE BAND IN CARBONATE ROCK FROM THE FOOT- WALL OF THE DE SMET ORE BODY ON THE 900-FOOT LEVEL



B. ORE LEDGE ON THE 1,000-FOOT LEVEL NEAR FOOTWALL SHEAR ZONE near the western wall. Plate III, *B*, shows the rather scant patches of carbonate interspersed with the quartz between blades of cummingtonite. Inasmuch as at other localities the cummingtonite may be seen as bands in carbonate-bearing schist, there is no reason to doubt that this almost complete replacement is simply a matter of degree. The cummingtonite has replaced not only the carbonate but also much quartz.

At the B. & M. shaft on the 400-foot level a chlorite schist associated with the small ore body there developed contains much carbonate with the quartz that makes up the bulk of the rock. The peculiar nodular, spongelike growth of the chlorite is unusual. (See Pl. IV, *A*.)

Specimen A from the Caledonia ore body on the 400-foot level, showing blades of chlorite in a groundmass of carbonate and quartz, is illustrated in Plate IV, *B*. An analysis showed the following percentages: $CaCO_3$, 0.7; $MgCO_3$, 2.5; $FeCO_3$, 11.6.

Plate V, *A*, illustrates the massive ore of the Caledonia ore body on the 500-foot level. It consists almost wholly of abundant cummingtonite, green mica, and chlorite with quartz.

Here and there throughout the mine a nearly pure layer of carbonate rock may be found interbedded with the more impure beds. Such a layer occurs on the 600-foot level near the Deadwood Terra shaft, and there is another on the 500-foot level. As is clearly shown by a partial analysis, this rock contains much carbonate, the percentages being, $CaCO_3$, 22.7; $MgCO_3$, 16.1; $FeCO_3$, 9.3; $MnCO_3$, 2.

An unusually good example of the carbonate-bearing ledge matter, shown in Plate V, *B*, was collected from the Incline ore body, where there is more structural evidence than in other parts of the mine to prove that all the ore bodies are merely metamorphic sedimentary beds. This specimen illustrates with particular perfection a banded carbonate and quartzose rock in which some of the carbonate bands are replaced by cummingtonite. In the illustration most of the granular gray material is carbonate, most of the white is carbonate and quartz, and the bladed mineral is cummingtonite. Other parts of the rock show less cummingtonite and more carbonate banded with quartz. Analysis gave the following percentages: $CaCO_3$, none; $MgCO_3$, 5.2; $FeCO_3$, 13.4; Fe_2O, none; limonite, 11. Calcium is lacking. No better petrographic proof is needed to support the argument that the main ore ledges are carbonate-bearing sedimentary beds.

The rocks near the Deadwood Terra shaft on the 500-foot level contain quartz, carbonate, and much carbonaceous matter. Plate VI, *B*, illustrates a purer bed of light-green rock clearly containing carbonates and quartz and sericite in large blades. A partial analysis showed the following percentages: $CaCO_3$, 20.9; $MgCO_3$, 10; $FeCO_3$, 16.1.

On the 700-foot level a carbonate-bearing siliceous rock makes up at least part of the small ore body mined near the Old Abe shaft. What were evidently layers of carbonate interbedded with quartz have been pulled apart and are now patches of calcite or dolomite. Some of the flowage lines are plainly visible in the photograph reproduced in Plate VI, *A*.

The footwall of the De Smet ore body on the 900-foot level is a light-gray rock of carbonate appearance, showing narrow bands of silicate minerals, such as those pictured in Plate VII, *A*. The carbonate bands are made up of quartz and carbonate, and carbonate is dispersed through the silicate areas. Biotite and green mica are very abundant.

On the 1,000-foot level a narrow ore body is composed near the footwall of a carbonate quartz rock with abundant chlorite. There is more carbonate than appears in the accompanying illustration (Pl. VII, *B*), for much of it appears white, like the quartz.

CHEMICAL ANALYSES OF ROCKS, MINERALS, AND MINE WATER

A number of analyses of rocks and rock-making minerals and mine waters from the Homestake mine have been published.[18] Some of these are reprinted and discussed below and corroborate my own observations.

Analyses of slates from Homestake mine

	18	19	20	21	22	23	24
Depth ... feet	Surface.	1,900	200	200	200	100	100
Pyrite (FeS_2)	Trace.	3.51	2.90	2.20	4.87	4.61	4.05
Silica	66.08	50.36	63.90	62.20	54.20	53.90	55.20
Alumina	16.22	12.00	12.84	12.45	12.20	12.21	12.32
Ferrous oxide [a]	5.55	15.45	8.20	.11	10.58	10.32	11.14
Manganese oxide	.04	------	------	------	------	------	------
Magnesia	1.88	2.46	2.26	1.63	.40	------	------
Lime	.36	1.17	1.32	2.28	1.76	------	------
Soda	1.30	.68	------	------	} 2.78	Trace.	Trace.
Potash	5.30	5.08	------	------		4.12	3.25
Loss on ignition [b]	2.90	6.98	6.13	7.74	10.05	9.35	10.16
	99.83	97.69	------	------	------	------	------

[a] A small proportion of the iron in No. 18, and a considerable proportion in the others, is in the form of ferric oxide; some specular hematite occurs in No. 19, and hematite and limonite in the others. All iron not combined as FeS_2 has been reckoned as FeO.

[b] Loss on ignition includes some sulphur from the pyrite. In Nos. 20 to 24 some of this loss is no doubt due to water taken up through alteration subsequent to the opening of the mine workings, some of the rock sampled having been exposed to moist air for 20 to 30 years.

The analyses given in the foregoing table are noteworthy in that lime and magnesia are low and that these rocks are, with the possible exception of No. 19, considered wall rocks.

[18] Sharwood, W. J., Analyses of some rocks and minerals from the Homestake mine, Lead, S. Dak.: Econ. Geology, vol. 6, pp. 729–789, 1911.

Analyses of chlorite from Homestake mine

	40a	41a	40b	41b	42	43
	Dark, as found		Excluding sulphide		Light	Calculated from formula
Silica	25.13	26.02	25.38	26.21	24.20	27.25
Alumina	24.98	23.76	25.23	23.92	20.90	23.05
Ferric oxide	Not sep.	1.88	--------	1.89	4.27	--------
Ferrous oxide	32.44	30.40	32.76	30.63	32.34	32.45
Magnesia	Not det.	7.99	--------	8.05	9.42	9.11
Lime	Trace.	.40	Trace.	.40	Trace.	--------
Water	9.50	8.73	9.60	8.80	8.39	8.14
FeAsS	1.02	.72	--------	--------	--------	--------
	--------	99.90	--------	--------	99.52	--------

Sharwood adds that sample No. 42 was associated with magnesian siderite in a specimen that was styled "massive ore" by Irving. I have no doubt that one of the carbonate rocks is here indicated. Chlorite would be a normal metamorphic derivative of such a rock. Several analyses of hornblende in the next table are likewise particularly pertinent in this connection.

Analyses of hornblende and asbestos from Homestake mine and of typical cummingtonite

	44a	44b	45	46	47	F	G
Silica	52.36	52.77	50.36	45.66	46.8	51.09	50.74
Alumina	1.54	1.55	1.86	6.87	5.02	.95	.89
Ferrous oxide	33.76	34.02	34.62	31.40	33.0	32.07	33.14
Manganese oxide	[a].45	[a].45	.62	--------	.31	1.50	1.77
Magnesia	8.10	8.16	9.86	9.20	9.50	10.29	10.31
Lime	.94	.95	Trace.	1.04	1.16	Trace.	Trace
Soda	--------	[a].40	.74	.50	--------	.75	.54
Potash	--------	--------	Trace.	.73	--------	Trace.	Trace.
Water	[b]1.68	[b]1.70	--------	.14	--------	3.04	3.04
Ignition loss	--------	--------	.73	2.05	2.90	--------	--------
Fe_7S_8	.89	--------	--------	--------	--------	--------	--------
	100.12	100.00	98.78	--------	--------	99.69	100.43
Specific gravity	3.387	3.37	3.28	--------	--------	3.42	--------

[a] Determined in another sample of similar material.
[b] Determined by Penfield tube.
44a. Hornblende from 800-foot level, light brownish white, in masses of small radial aggregates, containing a little pyrrhotite.
44b. Same, eliminating S as Fe_7S_8.
45. Asbestos from 1,100-foot level, long-fibered, white, silky, free from quartz.
46, 47. Dark impure masses of radiating hornblende, greenish black; appears to contain both chlorite and biotite with iron oxide.
F, G. Analyses of cummingtonite from type locality, Cummington, Mass., by J. L. Smith and G. J. Brush.

According to Sharwood,[14] this hornblende was described as tremolite by Irving and Emmons. "In thin section it is practically colorless or may show a faint tinge of green or brown, but it differs from tremolite by containing little or no lime and a much larger proportion of iron, while tremolite is essentially a lime-magnesian amphibole."

[14] Op. cit., p. 746.

Analyses of carbonates from Homestake mine

	48	49	50	51	52	53
Color of specimen	Brownish white.	Creamy.	Black.	Pure white.	Creamy.	Brown.
Depth feet	200	600	600	700	800	400
Percentage composition:						
Calcium carbonate.	99.45	87.50	53.05	49.12	0	1.19
Magnesium carbonate.	Trace.	7.05	40.10	18.08	22.5	6.93
Ferrous carbonate.	.55	5.68	6.85	32.47	77.5	90.30
Manganese carbonate.	None.	Not det.	Trace.	.11	Trace.	1.67
Percentage of impurities in sample.	1.3 (Slate and quartz).	6.2 (Quartz and slate).	63.5 (Silica, carbon, pyrite).	30 (Pure quartz).	8.6 (Chlorite, iron oxides, carbon, quartz).	.64 (Arsenopyrite, quartz, chlorite).
Association or mode of occurrence.	As crust on slate.	With coarse gold in vug lining.	Hornblende, pyrite, carbonaceous matter.	Chlorite, quartz, and arsenopyrite.	Quartz, arsenopyrite, pyrrhotite, hematite.	Chlorite, quartz, arsenopyrite.
Approximate molecular ratio:						
$CaCO_3$	1	20	9	7	0	1
$MgCO_3$	0	2	8	3	2	8
$FeCO_3$	0	1	1	4	5	80

This tabulation is based on analyses calculated to material soluble in dilute acid.

Several of these analyses are of particular interest. No. 50 was a black opaque material found in a number of specimens, usually in patches filling the spaces between crystallized minerals. It apparently always contains carbonates and carbonaceous matter, sometimes evidently graphitized. Magnetite or specularite is sometimes present; the latter is a form easily mistaken for graphitic flakes. Pyrite or pyrrhotite is usually present. The sample analyzed was apparently homogeneous, filling spaces between aggregates of radiating crystals of hornblende on the 600 level.

There is no doubt in my mind that this material was an original part of the rock. The ore was a replacement of a dolomitic schist.

No. 52 "was associated with quartz, arsenopyrite, and pyrrhotite in what is termed 'massive ore' by Irving." Some specimens formed rather large masses, black from included scales and plates of specular hematite and carbonaceous matter. One such mass contained coarse free gold, and fine gold was found in several specimens. This type is, to judge by appearances, common on the lower levels, occurring in the "massive" and "contorted" ore, in places associated with sulphides and chlorite. This rock is a magnesian iron carbonate. The cummingtonite is the natural metamorphic product of such a rock, and the residual carbonate was the determining factor in affording a rock susceptible of replacement by ore-bearing solutions.

No. 53 was brown carbonate from the West crosscut, Independence, short 400-foot level. It resembles some specimens of siderite, and similar specimens were found in some of the upper workings associated with more or less oxidized and altered ore, in some places filling cracks in barren pyrite. The particular sample analyzed was a granular aggregate of minute crystals having a texture like that of lump sugar and was associated with quartz, chlorite, and arsenopyrite in rock of the average value. The carbonate was seen to be strained and shattered; the cracks had been refilled with quartz.

All these observations by Sharwood are fully in accord with my own, noted in other places.

Analyses of waters from Homestake mine and near-by creeks

[Parts per million]

	Mine waters									Whitewood Creek, above Savage tunnel				Spearfish Creek, Lead city supply		
	Normal				Fire period, spring, 1907											
	26	27	28	29	30	31	32	33	34	35	36	37a	37b	38	39a	39b
Total solids	510	1,228	695		2,670	5,790	3,120		4,140	206	240			350	256	224
Silica	12	5	7						30					Trace.	[a] 10	
Alumina	2.6				Trace.	7.3			Trace.	Trace.	Trace.			Trace.		[a] 18
Ferric oxide			4						Trace.							
Ferrous oxide (in $FeSO_4$)		0	0		28	49			76	0	0			0	0	0
Magnesia	62	101	35		338	475			590		39			53	32	29
Lime	111	370	61		442	450			791		62			105	75	67
Soda	27	37	121		427	1,642	600		145							3
Potash	10		147													
Sulphuric anhydride (SO_3)	130	609	162	306	1,115	2,339	1,458	1,500	1,950	36.5	45	19	18	5	2.5	1
Chlorine	11	17	19	18	8	32			12	5				4	2	8
Carbonic anhydride (CO_2)[b]	100	73	139		347	600			334					154	115	89

[a] Some suspended matter included; the dissolved portion is chiefly silica.
[b] These figures represent CO_2 found in residues from evaporation and should be approximately doubled to give that existing in the original waters as bicarbonates.

26. 300-foot level, 1909.
27. 1,100-foot level, dry period, 1906.
28. 1,550-foot level, wet period, 1909.
29. Pump, B. & M. shaft, 1905.
30. Average sample after fire. Contains 0.0017 per cent of gold.
31. 1,250-foot level.
32. 1,100-foot level.
33. Above 300-feet level, north end.
34. 300-foot level, hot water, fire area
35, 36. Low water, 1907.
37a, 37b. High water, 1907.
38. November, 1906.
39a. May, 1911.
39b. August, 1911.

Sharwood says:[15]

Analyses of waters from the mine (Nos. 26–29), samples under normal conditions, as compared with water from other sources in the vicinity, show a considerably larger proportion of lime and magnesia. During the fire period this condition is even more accentuated. (Note particularly No. 34.) Contrast these analyses with Nos. 35 to 39, taken from the sources from which the water was taken to fill the mine at the time of the fire. The unusual amounts noted in the Spearfish Creek (Lead city supply) are probably due to the proximity of the overlying Paleozoic dolomitic sediments there prevalent.

The support that these data lend the thesis here set forth is clear.

STRUCTURE

GENERAL FEATURES

The pre-Cambrian rocks of the Black Hills comprise (1) a great thickness of metamorphosed sedimentary rocks; (2) basic igneous rocks which invaded others prior to metamorphism and are in consequence metamorphosed to amphibolites; (3) granite invading alike the metamorphic sedimentary and igneous rocks.

The Homestake ore bodies occur entirely within the metamorphosed sedimentary rocks, and as has been shown by field and laboratory observation, the idea that any pre-Cambrian igneous rocks are involved in their structure can be dismissed. Although metamorphosed basic dikes occur in the general vicinity of the mine, no pre-Cambrian dikes were observed in the mine, and none of the ore bodies are composed of such rocks. Granite likewise does not occur in the mine, though much quartz in veinlets and masses has been introduced into the rocks and is, no doubt, an end product of the cooling underlying granite. The structure of the Homestake ore bodies, therefore, must be explained wholly by reference to those principles which govern the metamorphism, folding, faulting, and mineralization of a series of sedimentary rocks.

A study of the field relations here and in other regions proves conclusively that where rocks are highly compressed at great depths a system of folds is evolved which have certain characteristics—namely, the major folds carry secondary folds upon their flanks, the secondary folds carry a tertiary system, the third system carries a fourth, and so on. In their large and in their minor characteristics, too, all these folds show notable resemblances. The folded beds are generally thicker at their crests and troughs than along their flanks. Cleavage has been developed across the bedding of the strata at the turns of the folds, nearly at right angles to the axial planes. Soft beds are more likely to be folded than hard beds, for hard beds may rupture and be pulled apart for long distances. All these features

[15] Op. cit., p. 738.

may be studied on the small folds, some of them may be observed on the intermediate folds, and others may be inferred with respect to the major folds after field study.

To decipher the intricacies of the folds near Lead it was necessary to trace on the surface a number of definite beds and to follow the folds of these beds underground in the mine. Although the pre Cambrian rocks are invaded by Tertiary porphyry and their outcrops are concealed in places by the Cambrian cover, it proved possible to establish the position of the major folds and of many of the minor folds.

The axis of a major anticline passes southward through Central City and swings southeastward near Lead. (See geologic map, Pl. I.) West of this major anticline is a major syncline with a southeastward-trending axis. West of this syncline are other major folds, the details of which have not been mapped.

The lowest rocks (stratigraphically) exposed at the surface in the major anticline are the impure calcareous and dolomitic schists and slates in Deadwood Gulch. Here the westward dips on the west limb of the anticline may be observed. These west dips give way to the prevailing steep easterly dips opposite the De Smet cut, the northernmost extension of the Homestake ore body.

On the geologic map (Pl. I) are represented the outcrops of a narrow band of quartzite and of several metamorphic dolomitic beds. These beds with interruptions may be followed from Bobtail Gulch to the Homestake open cut and may also be observed in many places underground in the mine. They have been traced also by Wright and Hosted through the great open cut. Some of the details of the folds in which they are involved are shown in the mapping of the major syncline, to the west. A shear zone occurs between the major anticline and major syncline, and its position is shown on the geologic map.

The relative position of the several open cuts of the Homestake system of ore bodies (see Pl. I) is suggestive of the structure that has determined their position. For example, the Caledonia ore body is formed by a tightly compressed double fold involving massive beds of cummingtonite rock. All the details of this folding have not been deciphered, but some of them are discussed below. The beds exposed in the Caledonia open cut are the same as those that may be observed in Deadwood Gulch, and they may be traced with interruptions beyond the Caledonia cut to the Clair cut. Thence they pass by folds to the Hercules cut. From the Hercules cut a prominent layer of cummingtonite schist can be traced directly into the great Homestake open cut, where it becomes involved in a number of anticlinal and synclinal folds that determine the shape and position of the several remaining ore bodies—namely, the Old Abe ore body, the Incline ledge, the Pierce ledge, the Main ledge, and the De Smet ledge, really an integral part of the Main ledge. (See Pl. I.)

If for a moment all the disturbance produced by the Tertiary porphyry intrusion and faulting is forgotten and it is kept in mind that the dolomitic schists do not everywhere make ore, the structure becomes very clear in its major features. From the Old Abe ore body the cummingtonite-bearing beds pass by way of a double fold, first synclinal and then anticlinal, into the synclinal fold that makes the Incline ore body. Thence the beds pass to the Pierce ore body, which is a tightly compressed anticlinal fold, and thence to the Main ore body, made up of a number of closely compressed synclines and anticlines which on their west side are involved in a shear zone. West of this zone these beds again appear in a major syncline and at a number of places are mineralized. If the ore bodies are viewed as mineralized portions of a series of folded beds of definite stratigraphic position, most of their characteristics are readily explainable.

Studies underground have corroborated surface observations. Although many places where underground observations might have been advantageous were inaccessible, it can be said in general that none of the observations it was possible to make failed to support in every particular the hypothesis of structure suggested by observations on the surface and set forth above. The underground observations only served to elaborate and make clearer the intricacies of the folding which were hidden by reason of surficial cover and igneous intrusion. For example, it is always possible underground to determine the all-important point whether the rocks at any particular place in the mine are below or above the quartzite horizon. It has been found that the ore-bearing beds are invariably either immediately or a short distance stratigraphically beneath this quartzite. The beds above the quartzite, chiefly garnetiferous schists, are everywhere barren of ore. The carbonate beds beneath the quartzite, however, particularly the cummingtonite rock, almost invariably accompany the ore—in fact, at most places such rock forms the so-called ore-bearing ledges. It is true that the chlorite schist and slate associated with the more highly carbonate rocks carry gold and are mineralized in places, but it is this calcareous magnesium and iron bearing series of metamorphic rocks that contains practically all the ore.

If, now, we consider in its simplest terms the theoretical disposition of a series of isoclinally folded beds superimposed upon a major anticlinal arch and cut by a shear zone on its west side, as described above, what dominant structural characteristics would such a series reveal?

1. The series should in all places present no stratigraphic anomalies, barring those that might be caused by faulting, intrusion, or completely overturned folds.

2. Folded beds would be thickened on the crests of the folds and thinned on the flanks.

3. Duplication of beds where several folds were pressed side by side would give the appearance of local thickening of that particular group of beds.

4. Brittle beds, such as quartzite, would be broken in places, particularly along the attenuated limbs of the folds.

5. The folds would have a characteristic pitch.

6. If the minor folds on such an anticline were tightly compressed and overturned and the series were cut by a mine level, as in the Homestake mine, observation on this one level alone would not reveal the true state of affairs. It would be necessary to determine from regional studies the position and nature of the major fold and the relations of the minor folds to it.

7. Where such a series of folds was cut by a fault the beds would terminate against it, and on the opposite side of the fault a different arrangement of beds should be expected, even though the same series of rocks might be present.

8. The minor overturned folds could be detected only by observations at their crests, and here, if the rocks were brittle, such as quartzite, joint planes parallel with the axis of the fold would simulate bedding and tend to deceive the observer, and if the rocks were soft, such as slate, a good cleavage would be developed across the bedding, also deceiving the observer.

9. The variety and complexity of individual small folds would be great: folds would die out and their place be taken by others, the attenuated limbs of folds would develop into faults, soft beds would in places be squeezed out completely between harder beds, and the observer would have to be constantly on his guard against being thrown off the track structurally by minor details. But if it is understood that these minor details indicate very clearly what has taken place on a large scale, then their usefulness will be great.

A study of the ore bodies from level to level affords abundant data supporting all the points enumerated above. These characteristics will be further discussed in the description of the ore bodies.

The major anticline with its many superimposed minor folds is cut by a large shear zone, which limits the mine on the west and may be regarded as the footwall of the ore body for many levels. West of this zone the major structure is quite different. Here the schists form a major syncline with isoclinal dips eastward, and on this major fold there are numerous minor folds. The rocks involved in this syncline are very similar to those in the major anticline just east of the shear zone, and there is every reason to believe that essentially the same beds are present.

The proof of the major synclinal structure lies in the convergence to the north of a number of beds of quartzite and highly metamorphosed dolomitic rock which can be traced on the surface. Their outcrops are represented on the map. Crosscuts underground disclose these quartzites, cummingtonite beds, and various schists similar to those east of the shear zone, and they are in places mineralized.

STRUCTURE SHOWN ON MINE LEVELS

The following descriptions of mine levels with maps are presented to clarify and illustrate the structural relations of the ore body. The maps are much generalized. No mine shafts are shown, nor any coordinate lines; stoped areas are not differentiated. On the other hand, the maps indicate the position of all the major folds, the relation of the folds to the shear

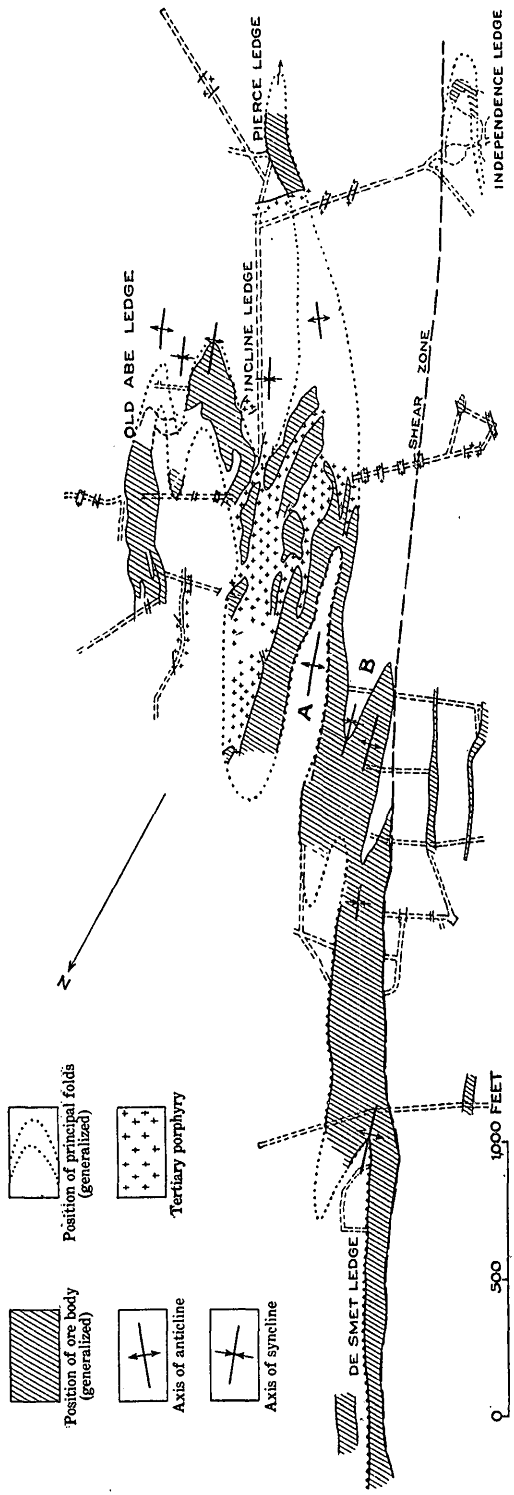


FIGURE 1.—Map of 200-foot level. (By Sidney Paige, L. B. Wright, and Joseph Hosted.)

zone, and the great fragmentation of parts of the ore body by porphry.

It should be borne in mine while studying these maps that all the ore bodies pitch to the southeast. The position of these ore bodies on each level must therefore be imagined as moved slightly to the southeast of its position on the next higher level.

The evidence of the essential structure is assembled for each level, in order that a picture may be conceived of the whole. Intricate folding and great dislocations by invasions of Tertiary porphyry almost compel such a treatment.

200-foot level.—None of the 200-foot level was examined. Most of it is now in the open cut, and but little of the remainder is accessible. There are, however, several features observable on the maps of this level worthy of comment. (See fig. 1.) The intrusive porphyry, which descends to the bottom of the mine, is here seen separating the main ore body from both the Incline and the Pierce ledges, and this relation is maintained throughout the mine. This level shows a number of folds, which at lower levels appear even more characteristically. A large horse of barren slate (A, fig. 1) separates two groups of ore-bearing beds, which converge to the southeast, indicating a sharp anticlinal fold. The syncline shown at B, Figure 1, is separated into two parts by a horse of slate entering from the southeast, made up of beds overlying the ore. This syncline terminates a short distance to the northwest.

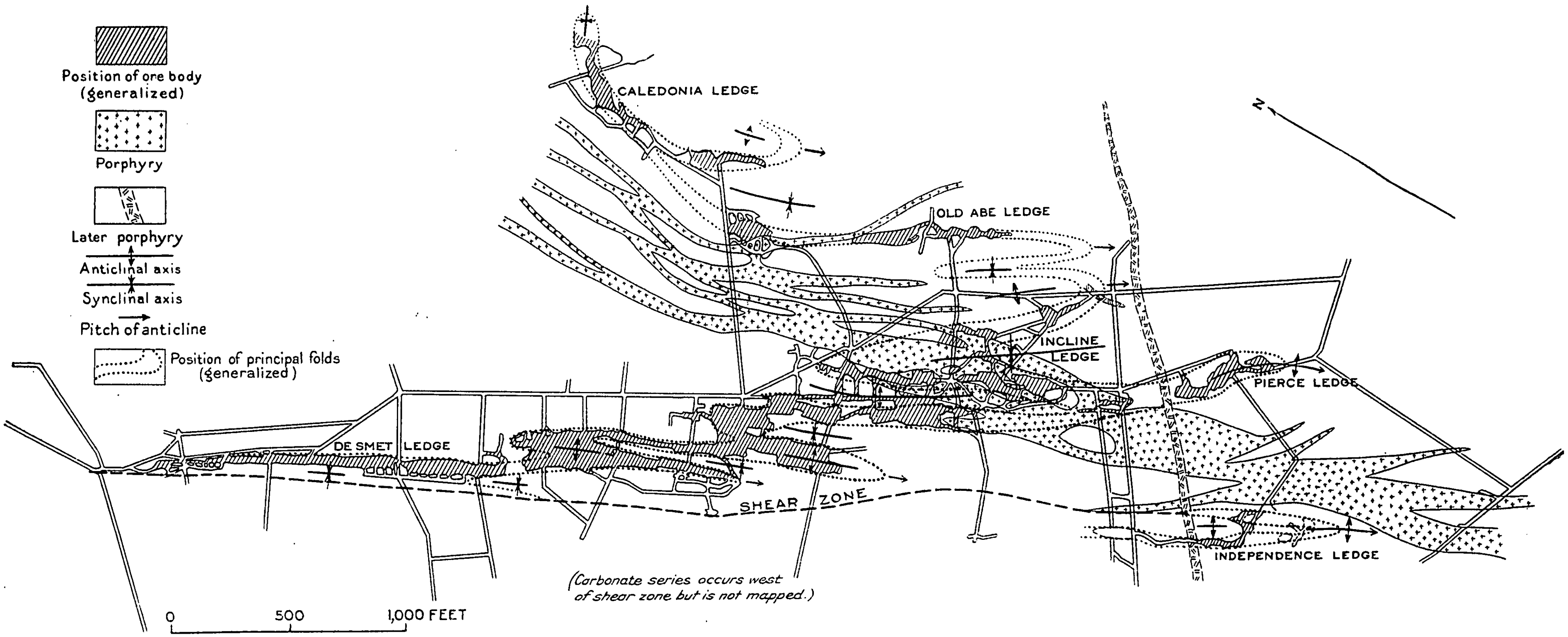
If it is kept in mind that the shear zone so clearly shown on lower levels passes across the ends of these folds on this level, a simple solution of the structure is obtained.

On this level the beds that make up the Old Abe ledge connect with the ledge immediately to the southeast by a double fold, though the mineralization was not sufficient to make ore.

The Pierce ledge is shown isolated from the other ledges, cut off by porphyry. This ledge (see p. 31) is a plunging anticline, broken on the west, on some levels, by a clearly defined fault, and it would connect with both the Incline ledge and the Main ledge were it not for faulting and the invasion by porphyry.

300-foot level.—Much of the 300-foot level (Pl. VIII) is now inaccessible, particularly the footwall country rock. On this level, however, are shown all the ore bodies which, when connected up, prove the folded attitude of the ore-bearing beds. Here, for example, the suggested connection of the Old Abe ledge northwestward and northward with the Caledonia is very clear. The Caledonia apparently terminates at the north in a very sharp synclinal fold.

On this level the plan of the ore body takes on the distinct appearance of a group of connected synclinal and anticlinal folds. The main portion of the ore body shows an alternation of barren



MAP OF 300-FOOT LEVEL

By Sidney Paige, L. B. Wright, and Joseph Hosted horses and connecting ore-bearing ledges. This arrangement is brought out by the dotted lines in Plate VIII. The upper of these lines (stratigraphically) represents the approximate position of the base of the barren quartzite series; the lower represents the approximate base of the cummingtonite series—that is, the beds that make ore. The Incline ledge is much broken by porphyry. The De Smet ledge is formed by the single limb of a closely appressed syncline cut on the west by a shear zone. It is probable that the Independence ledge, before shearing occurred, connected with the De Smet ledge. The connecting bed is now drawn out and pulled apart. There is evidence to support the view that the structure of the Independence ledge is anticlinal.

The porphyry is well shown in this level shattering the nose of the major anticline.

400-foot level.—On the 400-foot level, although porphyry dikes have broken the con-

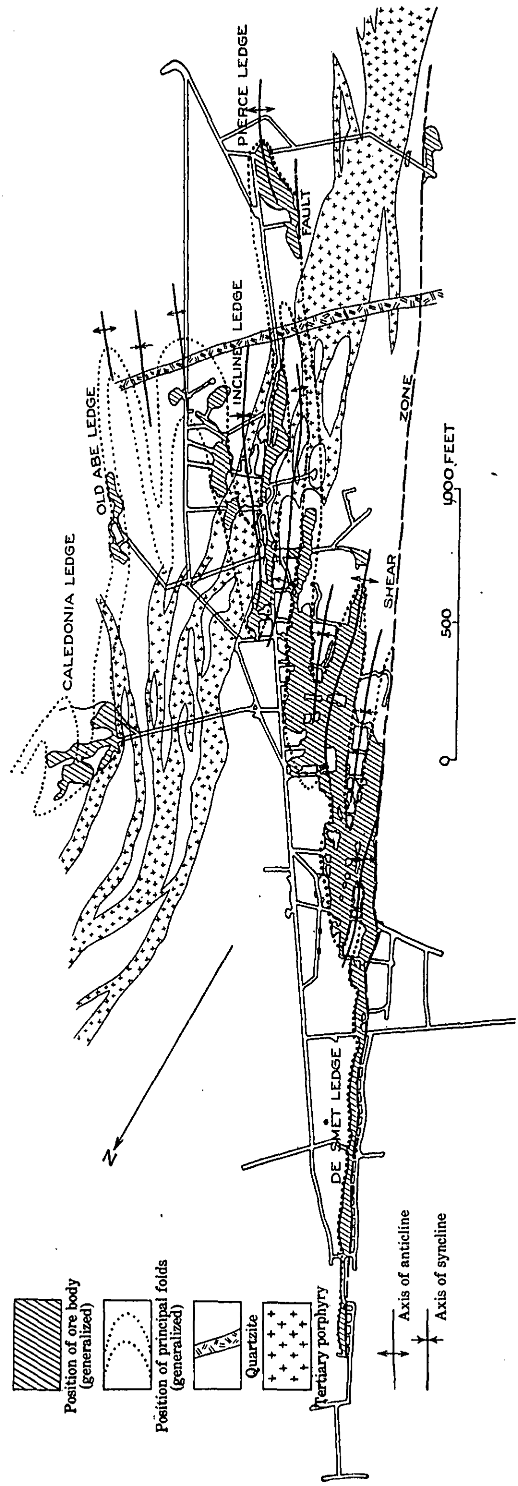


FIGURE 2.—Map of the 400-foot level. (By Sidney Paige, L. B. Wright, and Joseph Hosted.)

tinuity of the beds, it is possible to recognize even more clearly many of the major folds in which the ore-bearing rock is involved. (See fig. 2.) It is noteworthy that the Caledonia ore body can on this level be brought into the scheme of folding. On lower levels this relation appears even more clearly. Of the structural features shown on the map of this level some are determined by observations, others inferred from observations at higher and lower levels.

The overturned anticlinal nose of the Pierce ore body is established with certainty by the dips and strikes of the quartzite beds in the crosscut just south of the ore body.

The second syncline southeast of the Old Abe ledge—that is, the syncline that carries the Incline ore body—is greatly broken by porphyry, but it is one of the most persistent and clearest structural features in the mine. Observations show that the ledges on the eastern limb of this syncline fail in ore along the strike by decrease in gold tenor, but they are not terminated by a fold, like the Pierce. They connect with the Old Abe ledge through two minor folds. On a deeper level there is almost conclusive evidence that the western limb of the Incline ledge connected with the Pierce ledge prior to faulting. In this connection the great fragmentation of the major anticlinal fold by porphyry intrusions should be observed, and the near approach of its south end to the north end of the Pierce ledge.

The Old Abe ore body shows an evident trend toward the ledges of the Caledonia ore body. Developments have practically established the fact that the Old Abe ore body is connected with the Main ore body, on the other hand, by way of an anticline and a syncline.

Thus the entire set of ore bodies is brought into an orderly though complex system of folded ledges, broken by the porphyry invasion and otherwise disconnected as ore bodies because of lack of mineralization.

The footwall of the Main ore body on this level was inaccessible at most places, but enough was seen to make it practically certain that the long, narrow northern portion of the De Smet ore body on this level is a single bed, sheared along its west side. Such a shear accounts for the progressive shortening of this limb as depth is attained.

500-foot level.—Much of the 500-foot level was inaccessible, but the principal features of the structure could nevertheless be made out with a good deal of assurance, for they may be coordinated with folds on the levels above and below. (See fig. 3.)

The Caledonia ore body is considerably wider here than on higher levels. The Incline ledge is still much broken by the invasion of porphyry, and the Pierce ledge is still separated from the Main

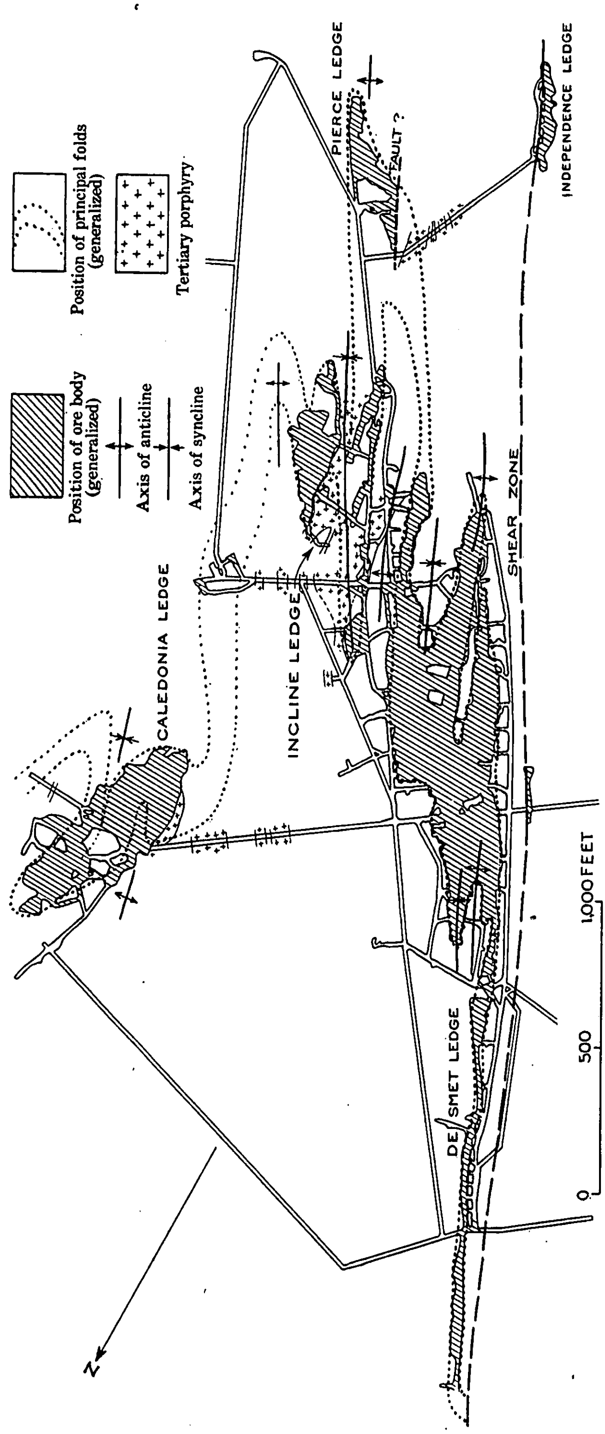


FIGURE 3.—Map of 500-foot level. (By Sidney Paige, L. B. Wright, and Joseph Hosted.)

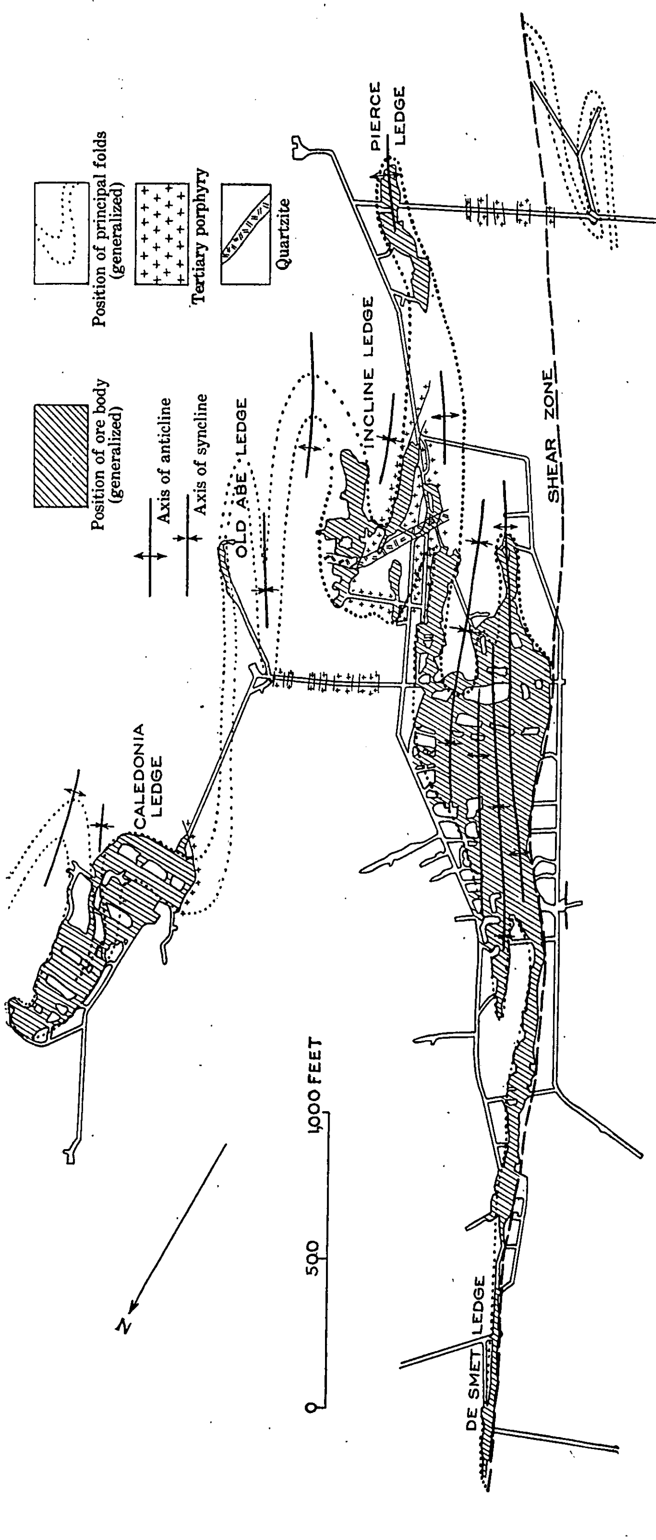


FIGURE 4.—Map of 800-foot level. (By Sidney Paige, L. B. Wright, and Joseph Hosted.)

ledge. The De Smet ledge remains a single bed, interpreted as the east limb of a close synclinal fold, the west limb of which has been sheared off.

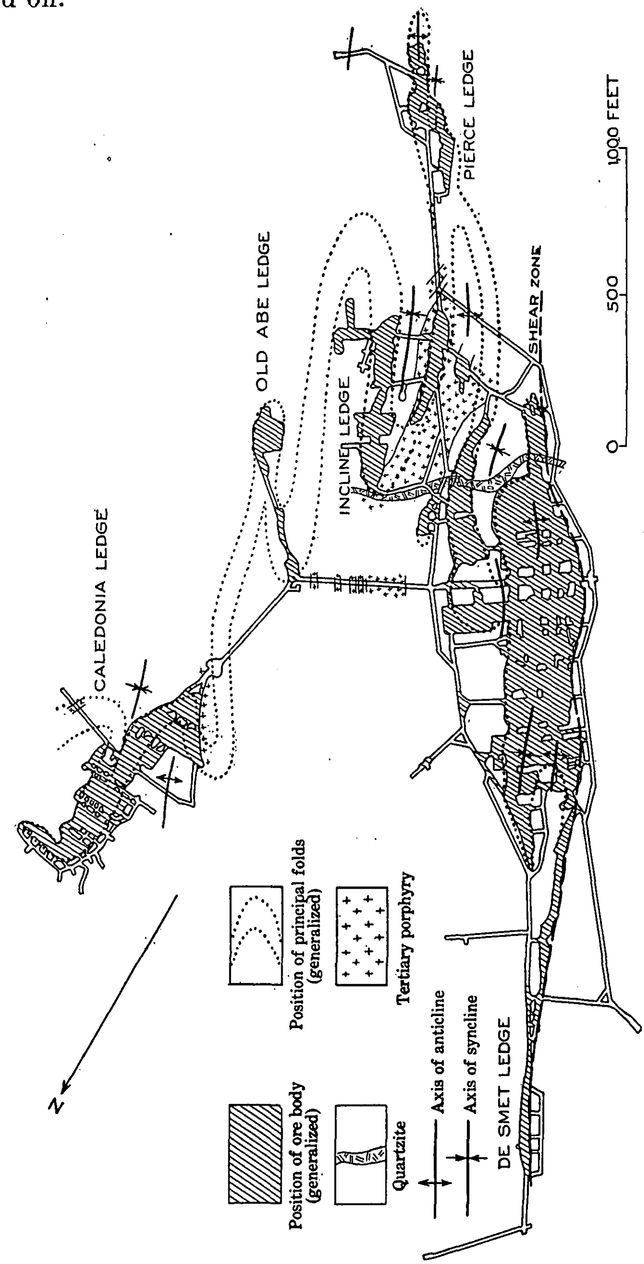


FIGURE 5.—Map of 700-foot level. (By Sidney Paige, L. B. Wright, and Joseph Hosted.)

600-foot level.—Many of the folds of the ore-bearing beds are very clearly shown on the 600-foot level. (See fig. 4.) The closely appressed synclinal fold of the Caledonia ledge is particularly clear. This fold is twisted sharply east at its northern termination.

The footwall slate curves around the ore-bearing bed in perfect conformity.

The Incline ledge is less disturbed by porphyry than on higher levels, and thus the syncline that forms its two limbs is more clearly recognized. It is more apparent, too, on this level that the anticline of the Pierce ledge would join both the Incline ledge and the Main ledge were it not separated by an intrusion of porphyry.

The folds of the main ore body are very closely appressed, and it is this remarkable repetition of beds that makes this wide ore body possible. A contrast is afforded by the very narrow De Smet ledge, where only a single bed is involved.

700-foot level.—At several places on the 700-foot level significant structural features may be observed. (See fig. 5.) For example, the anticlinal fold at the south end of the Pierce ledge may be clearly seen on this level. The beds of quartzite overlying the ore curve around the ore-bearing bed and plunge southeastward. The beds dip isoclinally to the southeast. The twist in the ore body on this level is similar to the twist on the 1,000-foot level and is due to a similar minor anticline and syncline. The straight west side and tapering north end on this level suggest a fault. In this respect the two levels, the 700 and the 1,000, are very similar.

The syncline of the Incline ledge presents about the same features as on higher and lower levels but is perhaps even more clearly shown.

The narrow, compressed syncline of the Caledonia ledge may be followed to the point of the fold, which is bent sharply eastward. The wall rock curves around the ore with perfect conformation.

The narrowness of the Main ore body at its north end is noteworthy on this level; likewise the certainty that strong shear zones are in some measure responsible for this condition. There is much, in fact, to suggest that the ore body is here bounded on both sides by faults. Pyrite zones may be observed both in the footwall and along the hanging wall at the extreme north end.

At the south end of the Main ore body quartzite beds occur in a crosscut opposite the end of the ore body. As these quartzites belong above and near the ore stratigraphically, and as they are not found a little farther north, it is very reasonable to suppose that they are faulted out by the principal shear zone passing along and near this western footwall.

800-foot level.—On the 800-foot level several of the major structural features are very clear. (See fig. 6.) Others, such as the anticline of the Pierce ore body and the nose of the major anticline of the Main ore body, were inaccessible and can simply be interpreted by analogy with other levels. The folds of the Main ore body on this

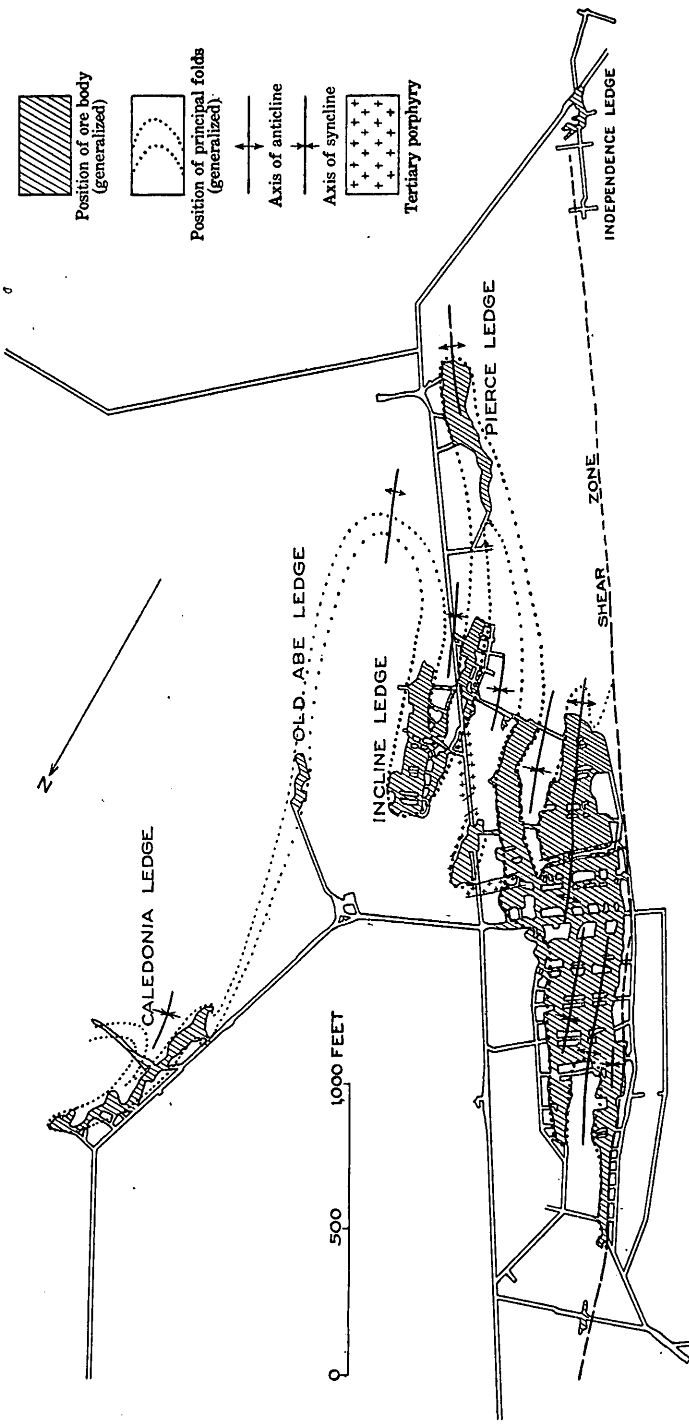


FIGURE 6.—Map of 800-foot level. (By Sidney Paige, L. B. Wright, and Joseph Hosted.)

level are nearly parallel with the footwall fault. Most of the footwall on this level was inaccessible, but quartzites were observed in a position on the footwall that suggests that they are cut off by a fault. Evidence of this fault or shear zone may be seen on this level

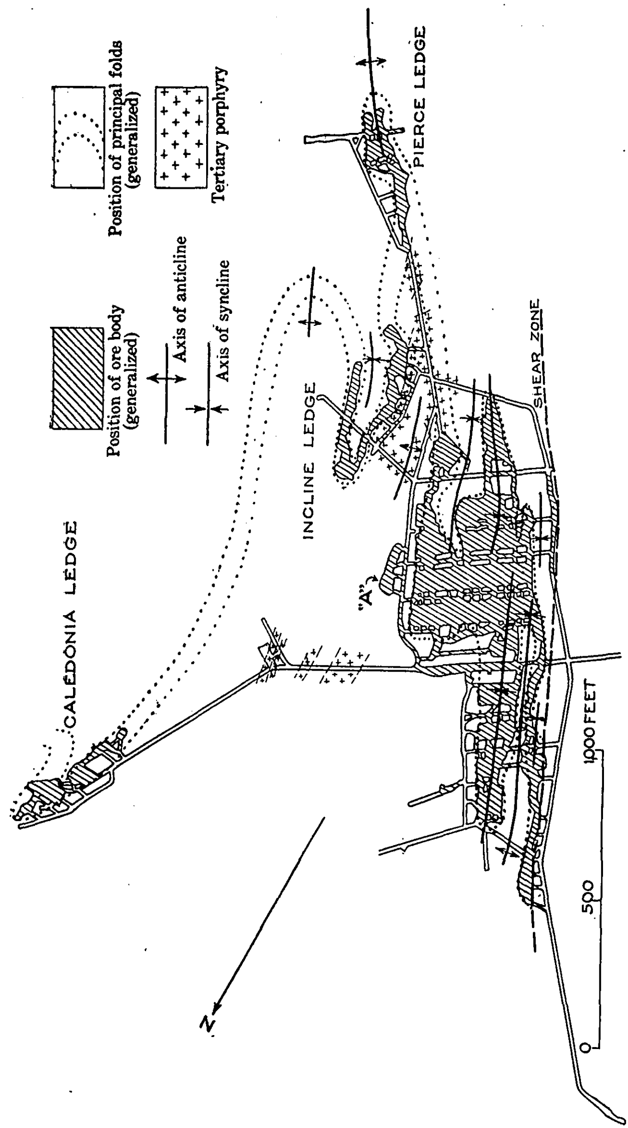


FIGURE 7.—Map of 900-foot level. (By Sidney Paige, L. B. Wright, and Joseph Hosted.)

far to the north, in the Highland crosscut, where brecciated pyrite zones appear.

The syncline of the Incline ledge is fully developed on this level. There is no development east of it to give any clue as to its connection with the ledge southeast of the Old Abe shaft, but it is believed to connect by way of an anticlinal fold, either simple or complex, somewhere in the region indicated by the dotted lines on Figure 6. As has been shown, this connection is clear on higher levels.

The form of the Incline ore body on this level is especially significant. The two limbs of the fold come together at the north end and diverge southward. This is exactly the form to be expected where a horizontal plane (the mine level) cuts a plunging synclinal fold.

The small ore body west of the Incline ledge is separated from the Main ore body and from the Incline ledge by porphyry, but undoubtedly it was at one time joined to both. Thus it may be considered structurally the northernmost extension of this particular syncline on this level.

900-foot level.—On the 900-foot level many of the major folds of the Homestake system are very clearly illustrated. (See fig. 7.) The syncline of the Incline ledge, with two limbs diverging southward, may be compared with the Pierce ore body, at the south end of which heavy quartzites appear on both sides of the ledge. This south end of the Pierce ore body does not show an anticlinal nose so perfectly as on the 1,000-foot level, and it is probable that the ore-bearing rock is leaner on this level at this point and that it was not mined out to the point where the wall rock curves around it. At the south face of the stope on this level the strike of the cummingtonite rock was still parallel to the walls.

The Incline ledge is bounded on the west by porphyry, which separates it from the Main ledge, of which there can be no doubt that it is a part. It is reasonable to suppose that the small ore body at the point marked A on Figure 7 is a part, and probably the northernmost extension, of the Incline ledge, as pointed out for the 800-foot level. At the extreme east end of the main crosscut traversing the Incline ledge cummingtonite rock appears, separated from the Main ledge by schist. This cummingtonite rock is probably the same ledge folded over on an anticline.

The twist in the middle of the Pierce ore body is no doubt due to the same small double fold so clearly to be seen on the 1,000-foot level, but this inference can not be verified, as on the 900-foot level the ore body was inaccessible at this point.

The narrow anticline at the south end of the Main ore body is indicated by the fact that quartzites curve around and cut off the ore at the south, thus forming the anticlinal nose. These quartzites may be observed in the main crosscut at the south end of the ore body. Naturally, in folding so close as that here involved, where for most of the distance on both flanks of a fold the dips are isoclinal, it is not easy to locate the precise point where the beds turn. But, as should be expected, there is a point on each flank of the fold where the dips become vertical, and such dips were observed in the mine. A nice corroboration of this hypothesis as to the structure was obtained by locating quartzites in the trough of the major syncline, which lies immediately east of this major anticline. The question may well be raised here: Why do the quartzites not follow the ore closely at all points? In the first place, not all the potential ore-bearing material has been rich enough to mine; second, variations in the composition of beds from place to place inhibited continuous replacement by solutions; third, there is no reason to expect that perfect regularity in replacement would occur.

The trough of this major syncline is clearly outlined by the extensive barren horse that projects northwestward into the Main ore body. In a mining operation of this type much barren rock must in places be removed and milled in order to obtain the richer portions, and therefore the configuration of the mined-out portions of the ore bodies does not in some places conform to the bedding planes of the " carbonate " beds. It must also be remembered that mineralization was not always confined to exactly the same horizon but occurred from place to place in a group of beds.

The quartzites on the west side of the Main ore body may be observed in the " draw hole " drifts off the main header, but their continuation to the north is truncated by a pronounced shear zone. This shear zone limits the ore at its west side, at the extreme north end of the Main body, and can be followed southward almost to the quartzites. It is reasonable to believe that the shear has cut off the quartzites and is a major structural feature. In fact, this fault or group of faults extends from the surface to the lowermost levels.

On higher levels, notably the 500, 600, and 700, there seems to be ample warrant for believing that the folds which constitute the Main ore body trend into and are cut off by the footwall fault or shear zone. On the 800-foot level, however, the configuration of the mined-out ore suggests that the major folds have swung more nearly parallel with the footwall fault, and it is also difficult to explain the configuration on the 900-foot level by any other hypothesis.

The interpretation of structure along the western footwall on this level that explains the most facts observed is as follows: The quartzites that may be seen along this wall occupy a sharp syncline, the axis of which is indicated on the map. Their termination to the north is due to this synclinal structure. The shear zone passes along and cuts out part of the western limb of this syncline, and the narrow band of ledge matter shown on the map expresses this fact.

1,000-foot level.—On the 1,000-foot level the folds of some parts of the ore body are clearly illustrated, but the folding of other parts is obscured by shearing. (See fig. 8.) For example, the anticlinal nose at the south end of the Pierce ore body is clearly indicated. The ore is terminated against a curving wall of schist that pitches down to the 1,000-foot level. It is the quartzite series that here makes both the footwall and the hanging wall of the Pierce ledge. A minor fold, not indicated on the map, near the middle of the ore body, accounts for the twist toward the west. These folds stand out very clearly in the mine.

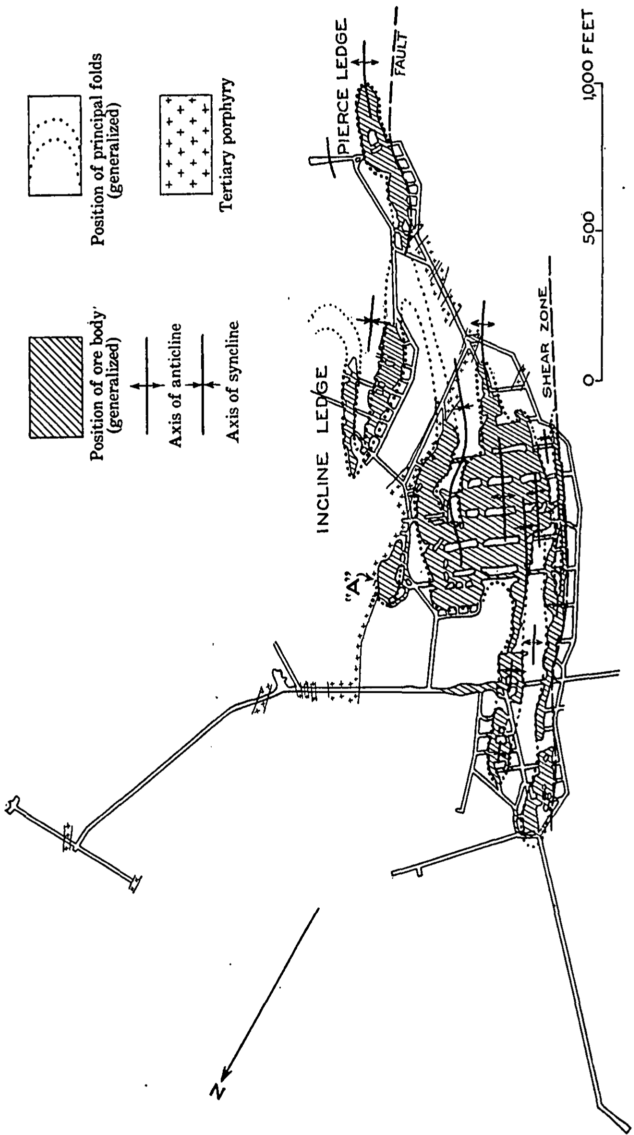


FIGURE 8.—Map of 1,000-foot level. (By Sidney Paige, L. B. Wright, and Joseph Hosted.)

The syncline of the Incline ledge is very clearly shown on the map of this level. The trough of the syncline is almost unbroken, and the ore body curves around it almost as perfectly as the ore curves around the nose of the Pierce anticline. The divergence of the limbs of this syncline is clearly shown. Porphyry separates this syncline from the Main ore body on this level, as it does on higher and lower levels, and the ore mass marked A on the map may well be a portion of the unbroken synclinal trough. The curve of the drift parallel to the ore is at least very suggestive of a fold at this place.

In the Main ore body the folds can not be so clearly seen, though the weight of supporting evidence from higher levels leaves no doubt of their presence. The quartzites, for example, may be observed in abundance along the main drift to the south of the Main ore body. This is the position in which they should occur if this southern point of the ore body is a major anticlinal nose. These quartzites may be observed in the successive crosscuts from the "main header" northwestward along the west side of the ore. They are believed to turn back and make the trough of a closely squeezed syncline, the axis of which is indicated on the map, for there is a narrow ore-bearing ledge of the normal cummingtonite rock west of the Main ledge, and it lies west of the quartzites. It is this narrow ledge that strongly suggests a faulted, western limb of a syncline with the quartzites lying stratigraphically above it.

A well-defined fault follows the west side of the Pierce ore body. It can be traced, as indicated on the map, at least three-fourths of the length of the ore body. The fault follows the Pierce ore body to lower levels and, it is reasonable to suppose, is in a measure the explanation of the severance of this ore body from the Incline ledge. Porphyry invasion also played a part in this break. On the 900-foot level the west side of the Pierce ledge (except at the north end and the extreme south end) was inaccessible, but porphyry at the north end separates the Incline ledge from the Pierce along lines suggesting that the porphyry invasion was influenced by or followed this fault.

MINERALIZATION

It has been shown above that the Homestake ledges form part of a series of folded carbonate-bearing schists, and that the form of the ore bodies arises from this fact. It will be shown below that the ores are replacement sulphide lodes, and the essential facts of their mineralogy will be described and illustrated. It is also of practical importance and scientific interest to determine the age of the ore deposit. Is it pre-Cambrian, Tertiary, or partly both? Systematic search for new ore bodies should be guided to a considerable degree by the decision reached. Evidence will be presented, as the ores are described, to show that the ore deposit was formed in pre-Cambrian time and probably enriched during Tertiary time—a satisfactory conclusion when it is remembered that this deposit is perhaps unique in point of genesis, and the mine is among the greatest gold mines of the world.

SULPHIDES

All the ores of the Homestake lode carry sulphides, and generally in the best ore the sulphides are abundant. In the order of their introduction they are arsenopyrite, pyrrhotite, and pyrite. Gold is associated with each of these minerals—that is, it occurs in them or in gangue minerals near by.

The sulphides have replaced portions of the carbonate schist series. Thus the deposit can not be described as a vein nor as a series of sheeted veins. It is distinctly a replacement lode. (See Pls. IX, *A*, *B;* X, *B*.) The sulphides in the main conform to the schistose structure of the rock. They follow bedding planes and lines of schistosity, and inference based wholly upon their general appearance would be that they had been intensely compressed and folded with the gangue minerals. Although such an inference would be only partly true, it can be shown to be warranted, in a measure at least, for evidence suggests that the sulphides were introduced before the final stages of the metamorphism.

There is abundant evidence that arsenopyrite was the first sulphide to be introduced. Its typical occurrence is illustrated in Plates X, *A*, and XI, *B*. In both illustrations it may be plainly seen, first, that arsenopyrite characteristically develops with crystal faces, replacing the body of the rock irrespective of the minerals that constitute it, and in Plate X, *A*, it is particularly clear that subsequent compression and movement have broken these crystals and by attrition rounded their edges. On these rounded edges and in cracks in the crystals pyrite has been deposited. (See fig. 9.) Nowhere was arsenopyrite observed cutting pyrite.

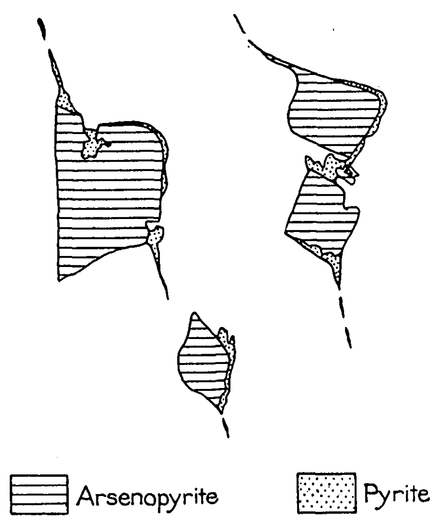


FIGURE 9.—Pyrite deposited on the rounded edges of arsenopyrite crystals, indicating the later origin of the pyrite

In one specimen pyrrhotite bears precisely the same relations to arsenopyrite that pyrite bears in the other specimen. Nowhere was arsenopyrite observed cutting pyrrhotite. It follows, therefore, that pyrrhotite is also later than arsenopyrite. In some large arsenopyrite crystals the arsenopyrite incloses numerous small masses of pyrrhotite. (See fig. 10.) These masses of pyrrhotite may be regarded either as poikilitically inclosed in and earlier than the arsenopyrite, as contemporaneous with the arsenopyrite, or as of later introduction. With the pyrrhotite are small masses of dark silicate. They also may have either of the above-stated three relationships. But, as shown above, there is evidence that compression of the schists continued after the introduction of arsenopyrite. Further evidence lies in the tiny cracks that traverse arsenopyrite crystals and that are filled with dark silicates and quartz. (See fig. 10.) These indicate that solutions were very active, and that silicate formed while arsenopyrite crystals were being broken, or just after

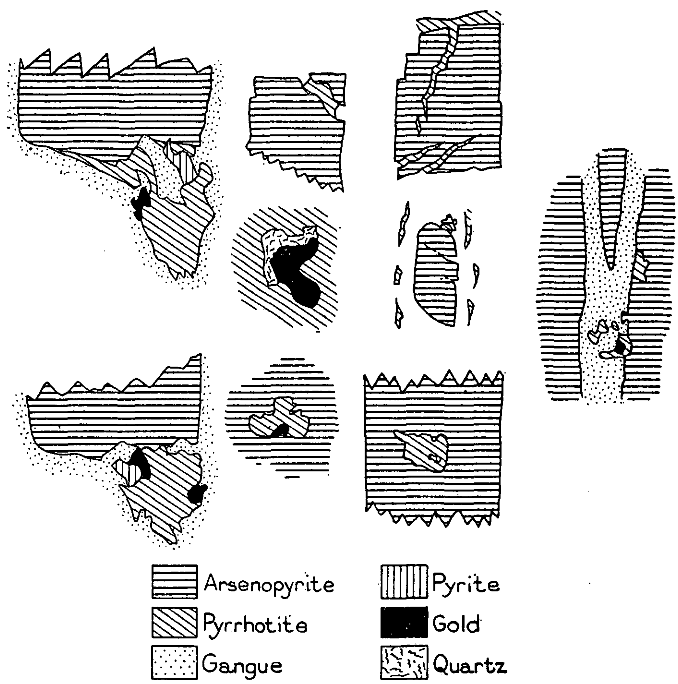
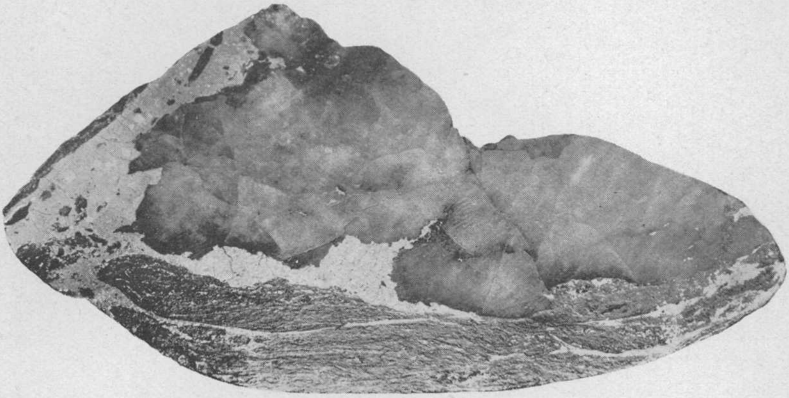


FIGURE 10.—Relation of pyrite and pyrrhotite to arsenopyrite. The arsenopyrite is replaced by pyrrhotite and dark silicates in small irregular masses and cracks

that event. If this was so, then the probabilities are that both the pyrrhotite and some of the dark silicate are later than the arsenopyrite.

These facts seem to prove that arsenopyrite was introduced at a late stage of the metamorphism of the schists and was partly deformed and that shortly afterward pyrrhotite and pyrite were introduced.

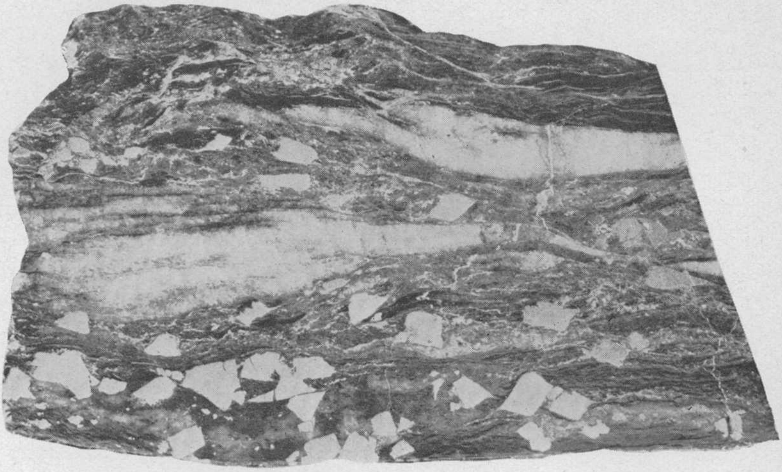
It may be readily shown that pyrite is later than pyrrhotite. Pyrite replaces pyrrhotite and occurs as veinlets cutting pyrrhotite and filling angles in groups of pyrrhotite crystals. In Figure 11 some of these relations are illustrated. Numerous grains of pyrite occur



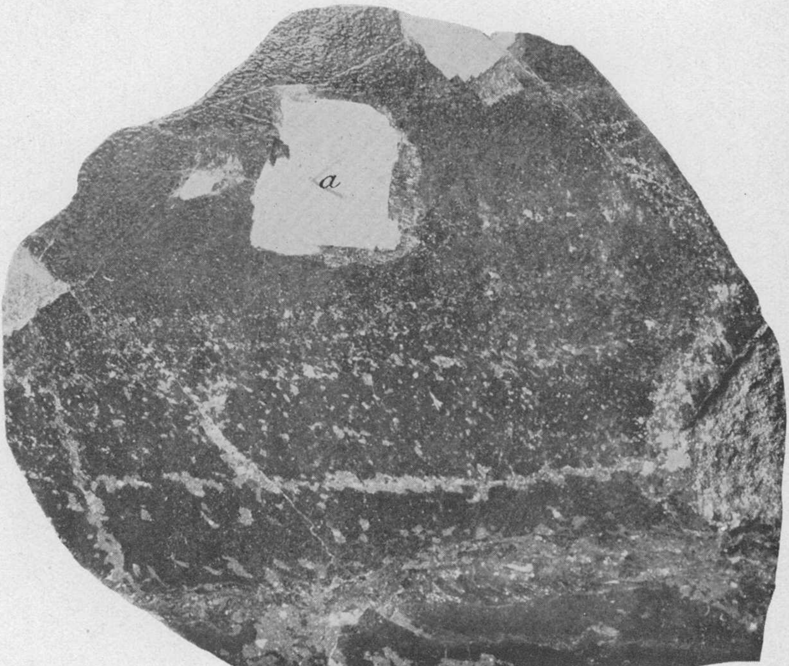
A. PYRRHOTITE ORE FROM THE 900-FOOT LEVEL

Note pyrite crystals in pyrrhotite. The pyrrhotite follows the schistosity of the rock and is later than the large mass of quartz

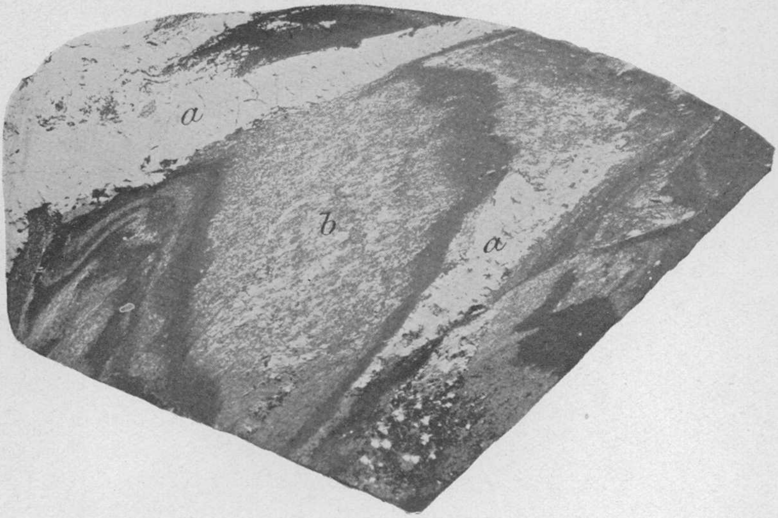
B. PYRRHOTITE ORE



A. ARSENOPYRITE CUT BY PYRITE

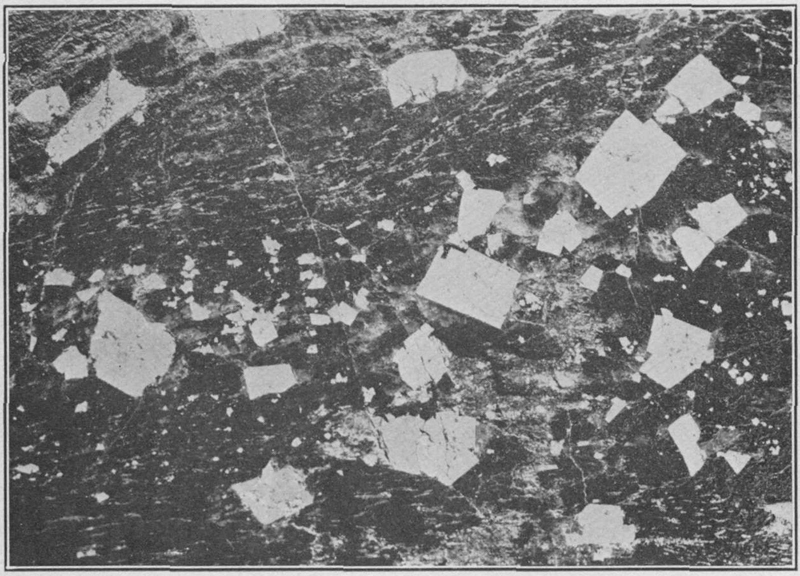


B. PYRRHOTITE, PYRITE, AND ARSENOPYRITE (*a*)



A. SHEARED SULPHIDES

a, Sheared pyrrhotite; *b*, mixture of slate and pyrrhotite



B. ARSENOPYRITE CUT BY PYRRHOTITE

associated with gold upon their borders, replacing pyrrhotite. This association of gold and pyrite in such a position practically proves that the pyrite was introduced later than the pyrrhotite.

Of special interest is the discovery of two generations of pyrite. Veinlets of pyrite were observed cutting pyrite grains of the first generation. These are illustrated in Figure 12. Inasmuch as it is known that great quantities of pyrite were deposited in Cambrian

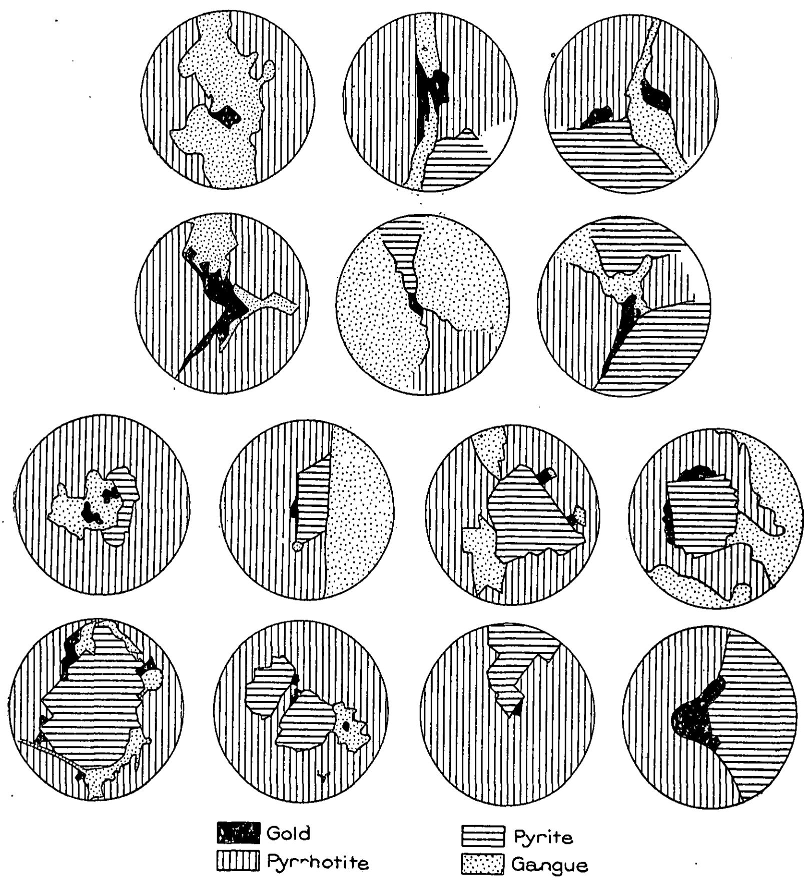


FIGURE 11.—Relation of pyrite and gold to pyrrhotite

beds overlying the Homestake lode, it is gratifying to find concrete evidence of the second generation in the Homestake ore.

There is further evidence strongly supporting the view that the first mineralization occurred in pre-Cambrian time. A large zone of shearing follows the west side of the Main ore body. It has been shown above in the discussion on geologic structure that this shear zone is related to close folding and is of pre-Cambrian age. It occurs where a closely appressed anticline abuts against a major syncline.

On several levels, particularly the 900-foot, a mashed zone of slate in places 2 feet wide may be observed in a position corresponding to the position of this shear zone. Within this 2 feet of mashed slate intense folding and shearing has deformed the sulphides, pyrrhotite and pyrite, and also the gold. Masses of pyrrhotite are sheared at their edges and drawn out in a finely divided state and mixed with slate. Gold has suffered similarly. The whole proves a movement under severe compression. The occurrence is illustrated in Plate XI, *A*.

No such forces as are indicated here have operated in Tertiary or later time in this region. On the contrary, it is probable that tensional stresses were dominant at that time.

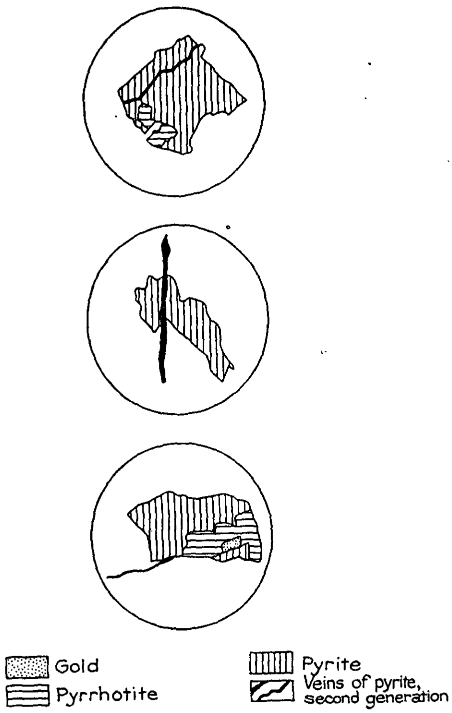


FIGURE 12.—Pyrite formed during two periods of deposition

MAGNETITE

The occurrence of magnetite rather abundantly in several specimens of ore and clearly as a mineral introduced later than pyrite affords further evidence of the pre-Cambrian age of the first mineralization. The magnetite occurs as fringing masses and crystals around pyrite grains, filling reentrant angles in groups of pyrite crystals, and cutting or replacing crystals of pyrite. Magnetite has not been noted in the Tertiary ores overlying the Homestake lode, but it is a common mineral associated with the granitic invasion of the southern hills, both in pegmatite and in quartz veins. I regard it as of this association in the Homestake ores and therefore as confirmatory evidence of the pre-Cambrian age of the deposits.

GOLD

Most of the gold in the Homestake ores occurs free, and about 70 per cent is caught by amalgamation. Polished sections of sulphide ore almost invariably show free gold This gold may be in the gangue minerals, as thin flakes—for example, along the cleavage surfaces of chlorite; or it may be in quartz or in carbonate; or, as in many places, it may be more closely associated with sulphides. It has been noted in arsenopyrite, in and on the borders of pyrite grains and abundantly replacing or accompanying pyrrhotite.

In Figure 11 is illustrated the occurrence of gold associated with pyrite and replacing pyrrhotite. To a noteworthy extent the gold occurs at the borders of the pyrite grains but in the pyrrhotite.

Gold in pyrrhotite with a gangue of quartz occurs in veinlets cutting arsenopyrite, also gold and pyrrhotite later than but associated with arsenopyrite at the borders. Gold in veinlets cutting pyrrhotite or between pyrrhotite and pyrite is illustrated in Figure 10.

A number of drawings copied from Sharwood also illustrate the occurrence of gold. (See figs. 13–18.) It seems probable from these illustrations that gold came in with both pyrrhotite and pyrite, in pre-Cambrian time, and it will be shown below that probably some very fine gold, possibly associated with telluride, was introduced in Tertiary time, enriching the pre-Cambrian deposit.

The introduction of the sulphides and gold in pre-Cambrian time is believed to have been directly related to the last stages of metamorphism of the schists and connected with the invasion of granite. The statement that the sulphides appear in a certain sequence expresses their dominant relationships. It is probable that no great time interval separated the introduction of the several sulphides and the gold—that some gold was introduced with pyrrhotite, and more later with pyrite. Quartz also was no doubt introduced at several stages, or continuously, and the silicates that make up the body of the rock were no doubt undergoing change throughout a considerable period, while sulphides were being deposited.

DIFFERENCES BETWEEN THE TERTIARY GOLD ORES[16] IN CAMBRIAN DOLOMITES AND ORE OF THE HOMESTAKE LODE

Inasmuch as the question arises, Are not the Homestake ores of Tertiary age? it is important to point out that there are striking differences between the gold ores of Tertiary age that replace the Cambrian dolomites overlying the Homestake lode and the ores of the Homestake lode proper. These differences are of two sorts—differences in mineralogy, emphasized by the need of different metallurgic treatment, and differences in silver-gold ratio of the bullion. The Tertiary ores, occurring in certain areas where vertical fractures traverse the Cambrian dolomites and sandstones, are pyritic replacement deposits carrying varying but minor amounts of arsenopyrite. Both pyrrhotite and magnetite, the former so important in the Homestake lode, the latter shown to be later than pyrite in the Homestake ores, are absent from the Tertiary ores.

[16] For a very complete description of the Tertiary siliceous ores see Irving, J. D., op. cit.

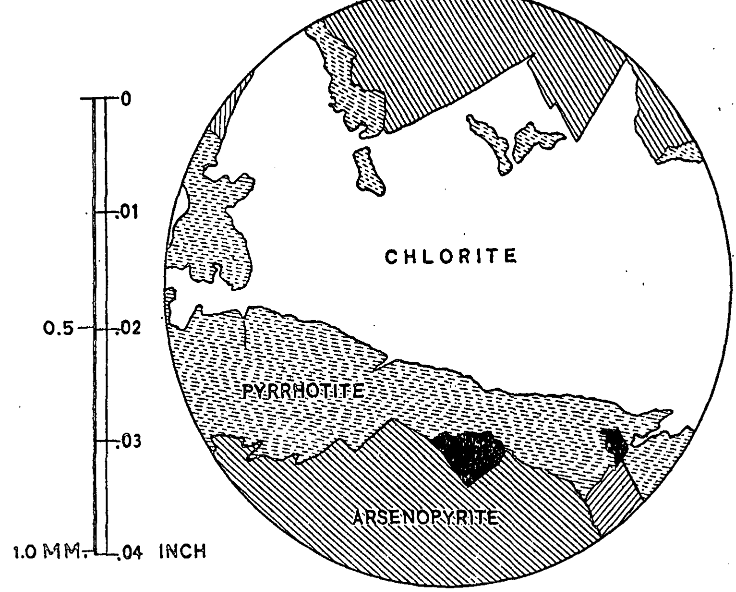


FIGURE 13.—Grains of gold at contact of pyrrhotite with crystals of arsenopyrite in dark chlorite. (After Sharwood)

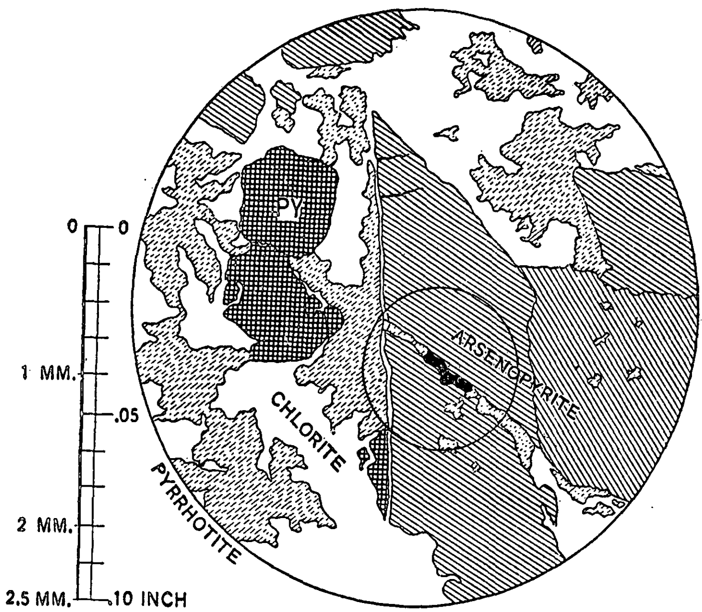


FIGURE 14.—Grain of gold and accompanying pyrrhotite filling crack in crystal of arsenopyrite in mass of dark chlorite. Much pyrrhotite present in irregular masses, and some pyrite in compact grains. No quartz observable. (After Sharwood)

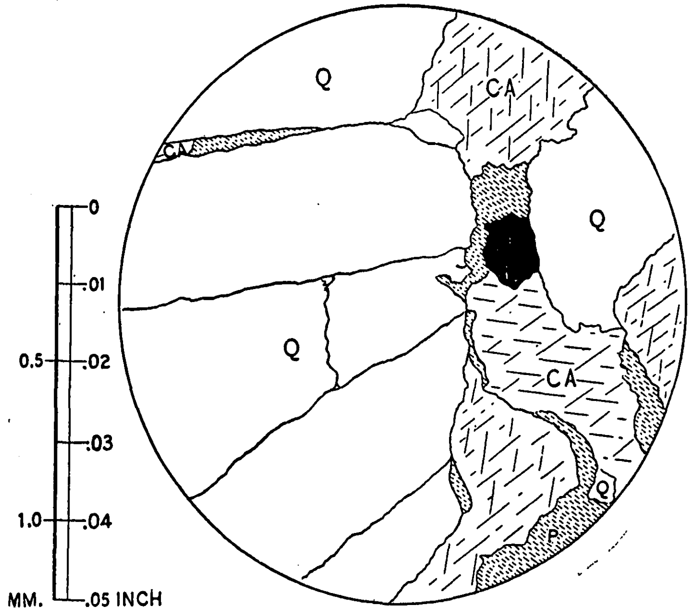


Figure 15.—Grain of gold with pyrrhotite in iron-manganese carbonate (CA) and very coarse grained transparent quartz (Q). "Massive ore." (After Sharwood)

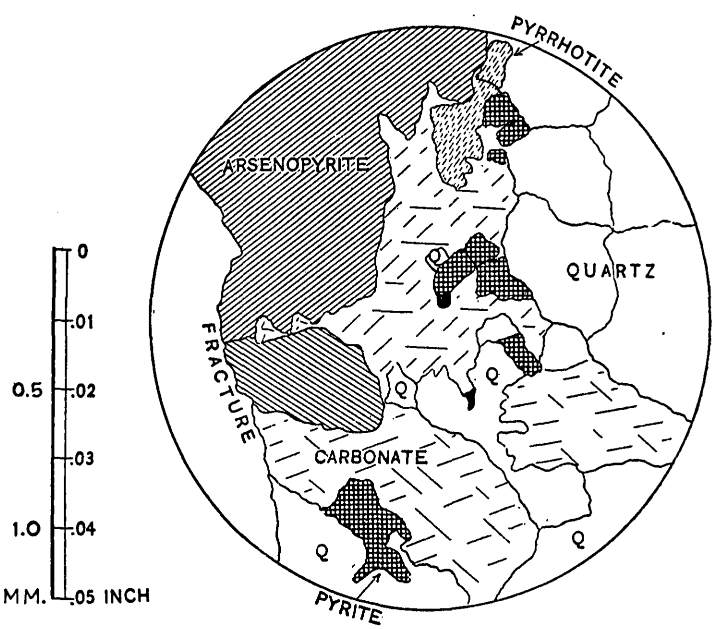


Figure 16.—Small grains of gold with a little pyrite and pyrrhotite, in scattered carbonate, with coarse-grained transparent quartz and arsenopyrite. (After Sharwood)

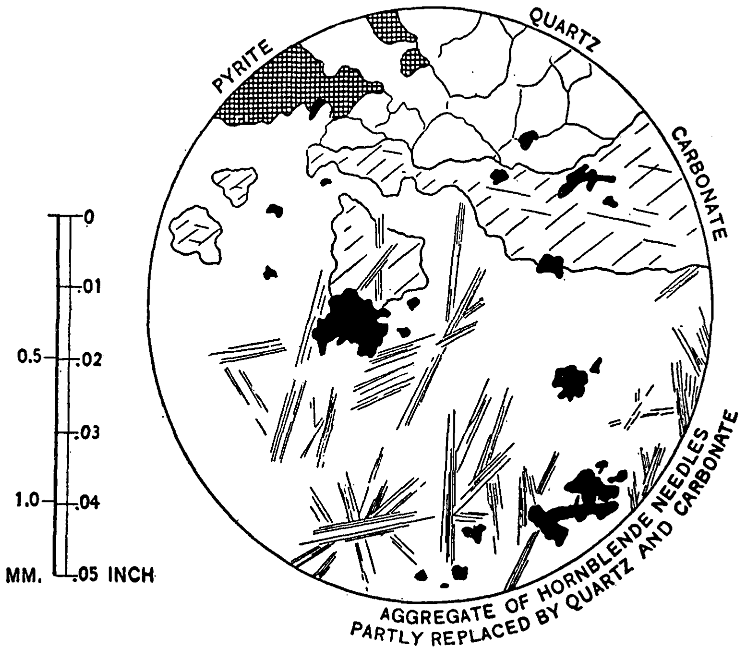


FIGURE 17.—Gold with quartz in mass of hornblende. Hornblende in radiating aggregates, at this point invaded and largely replaced by quartz, with occasional pyrite and scattered masses of iron-magnesium carbonate. (After Sharwood)

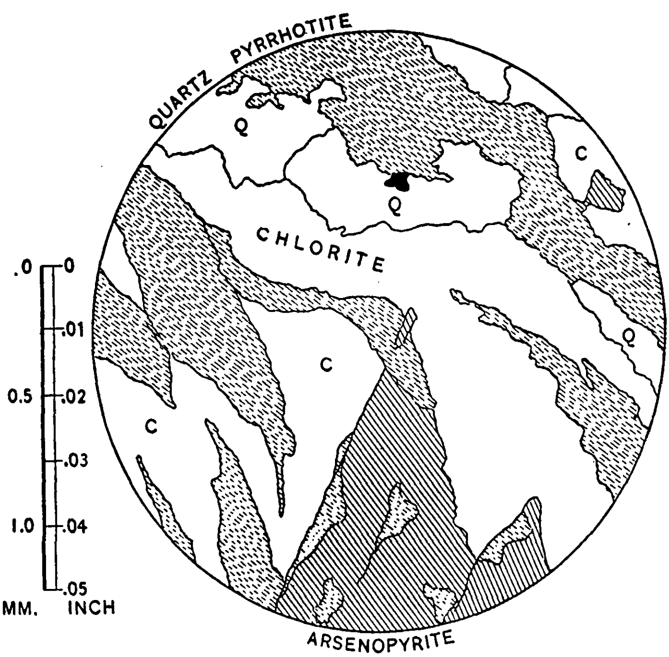


FIGURE 18.—Small grain of gold with transparent quartz (Q) and pyrrhotite in mass of chlorite (C). Much pyrrhotite present in very irregular masses, and arsenopyrite showing crystal outlines and small inclosures of pyrrhotite. (After Sharwood)

The gold of the Cambrian ores (except the conglomerate ore, discussed further below) is "so fine [fine grained] that no gold could be obtained in the pan, an almost universal characteristic of these ores."[17] This is quite the opposite from the condition in the Homestake mine, where much gold—70 per cent, more or less—is readily caught by direct amalgamation.[18] The explanation of this difference probably rests on the fact that in the ores of Tertiary age the gold occurs as a telluride, whereas in the pre-Cambrian ores at least 70 per cent is free gold. F. R. Smith[19] has shown that tellurium is an

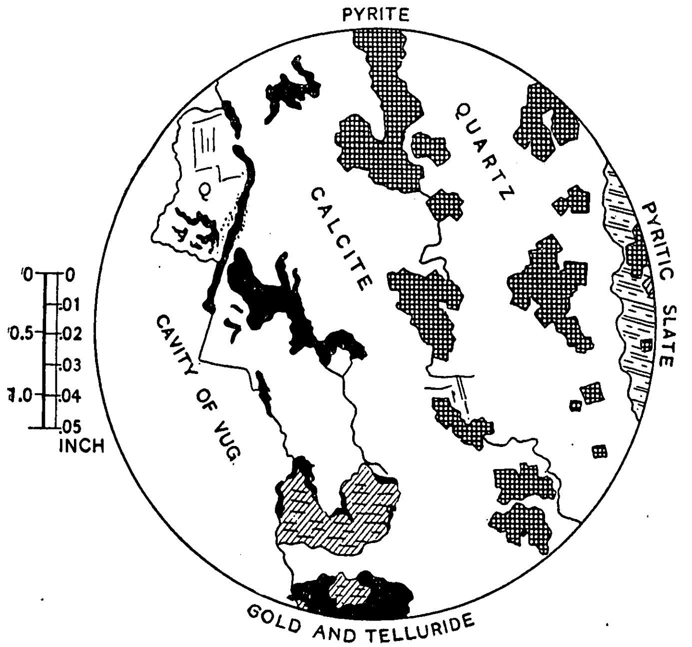


FIGURE 19.—Telluride containing bismuth in contact with free gold. (After Sharwood)

abundant constituent of the Tertiary ores and suggests that sylvanite is probably the telluride present. Typical samples yielded as high as 8.426 ounces of tellurium to the ton, and the analysis of nine different samples showed the following average percentages: Tellurium, 59.97; gold, 7.64; silver, 32.39. At the Dacy mine the percentages obtained "approximate the composition of sylvanite"—tellurium, 61.20; gold, 36.27; silver, 2.53.

In the Homestake ores tellurides are rare, though they have been noted. (See fig. 19.) It is possible that the portion of the gold caught by cyaniding may be present partly in the form of tellurides.

[17] Devereux, W. B., The occurrence of gold in the Potsdam formation, Black Hills, Dakota: Am. Inst. Min. Eng. Trans., vol. 10, p. 475, 1881.
[18] Sharwood, W. J., op. cit., p. 775.
[19] Smith, F. R., The Potsdam ores of the Black Hills of South Dakota: Am. Inst. Min. Eng. Trans., vol. 27, pp. 404–428, 1897.

Notable differences are mentioned by Sharwood[20] between the silver-gold ratio of Tertiary ores in the vicinity of the Homestake lode and the silver-gold ratio of the Homestake ore. Ratios of 5, 10.58, 11.4, and 4.1 to 1 were noted in the Tertiary ores, whereas in the Homestake ores the average is about 0.215 to 1 for bullion caught on the plates and about 0.433 for bullion recovered by cyaniding.

The facts set forth above clearly support the view that the first mineralization of the Homestake lode occurred in pre-Cambrian time. It is very probable, however, that some enrichment of the lode took place in Tertiary time. The evidence for this enrichment, though meager, may be summarized as follows:

Tellurides, though rare, have been noted in the Homestake ores. Assays are reported by Hosted and Wright to be somewhat higher for material near porphyry dikes. Replacement deposits of gold occur in the Cambrian dolomites overlying the Homestake lode, and it is inherently probable that the solutions which passed upward through the vertical fractures that led to these Tertiary ores deposited some gold in the pre-Cambrian rocks. A rough measure of this amount may possibly be expressed by the proportion caught in cyaniding.

FOSSIL PLACER DEPOSITS IN CAMBRIAN CONGLOMERATES

It is desirable to weigh the evidence pointing to the existence of a pre-Cambrian ore body cropping out at the time the Cambrian conglomerate, sandstone, and dolomite were laid down—that is, to examine the validity of the statement that fossil placer deposits derived from the Homestake lode occur in the basal Cambrian conglomerates.

Irving,[21] following Devereux,[22] has presented evidence to show that fossil placers actually exist, but an impartial and critical review of Irving's statement and the facts that he presents raises doubts not as to the probabilities of the case but as to the conclusiveness of the argument on the basis of the conglomerate ores alone. The main points made by Devereux and Irving will be very briefly presented.

In describing the gold-bearing conglomerates Irving says:

> 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 it is so prominent a feature of the series that it has been recognized as a separate formation. * * * There are two localities where it attains an unusual thickness. The first is known as Cement Ridge and is on the west side of Spearfish

[20] Op. cit., pp. 783–784.

[21] Irving, J. D., and Emmons, S. F., Economic resources of the northern Black Hills: U. S. Geol. Survey Prof. Paper 26, pp. 98–100, 1904.

[22] Devereux, W. B., The occurrence of gold in the Potsdam formation, Black Hills, Dakota: Am. Inst. Min. Eng. Trans., vol. 10, pp. 465–475, 1882.

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 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. * * * 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. * * * 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. * * * 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 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 bedrock. 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.

Up to this point it is clear that Irving regards gold in these deposits as of detrital origin. His next statement is the first to cast doubt upon this hypothesis. He continues:

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. * * * 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 postintrusive origin. This would place the pyrite 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.

To quote directly from Devereux,[23]

In general we find much the same variations of quantity as are shown in the ordinary gravel placer. The local channels referred to show the same alternations of rich and poor material, due to different conditions of current, and the universal occurrence of the greater part of the gold near the bedrock. In general only 5 or 6 feet in thickness will pay for mining and milling. * * * The gold has 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 cementing material of the conglomerate was generally oxide of iron, and the gold which had lain on bedrock was often attached to the overlying boulders by this medium. 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 boulders, or with pebbles of hematite. The latter were seldom found without gold being attached to 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. * * * The fineness of this gold is greater than that of the quartz veins, as is generally the case with placer gold.

With the facts thus far seen to be in accord with the position taken, we have another source of proof, in that we find in these same conglomerates gold which has undoubtedly been precipitated from solution in situ. I have several times split open pieces of decomposed talcose schist and found in the cleavage plane a continuous thin film of gold. Moreover, the schist underlying one of these deposits has been found to carry sufficient gold to pay for milling, although after a depth of 10 feet has been obtained it seems to give out. Specimens from this locality show the gold in thin flakes, seldom coarse, and pan tests show the gold to be fine like chert. On the other hand, where the

[23] Op. cit., p. 468.

slate has been very soft cement gold will be found to have worked down into the crevices for several feet. It can be washed out in a pan from the fragments without crushing and then appears like smooth brown gravel, so continuous is the coating of red oxide of iron. In addition we have gold undoubtedly precipitated in the quartzites of this series at a period much more recent, and this gold presents none of the characteristics of the cement gold.

It is apparent to the critical reader of Irving's and Devereux's reports that many of the facts presented above suggest strongly that placer gold actually existed. These may be summarized as follows:

There is stratigraphic proof that a pre-Cambrian reef existed along the outcrop of the Homestake lode. The conglomerates were derived from this reef.

The conglomerates carried coarse gold said to resemble detrital gold from other places, and its location was apparently both within the conglomerate and below in the bedrock, to which it was carried by gravity—that is, its position was due to its weight. The gold, too, carried less silver than the lode gold.

The gold in the Cambrian formation everywhere except in the conglomerates is very finely divided, and most of it can not be recovered by amalgamation. The heavy matrix of pyrite (or limonite where oxidized) that accompanies the gold-bearing conglomerates suggests that the conglomerates were derived from a pyrite-bearing lode, though it is problematic whether all the pyrite would not have been oxidized, and it is probable that after the invasion of these rocks by Tertiary volcanic material and the passage through them of a certain amount of gold-bearing solutions derived from the porphyry, the detrital pyrite may have been introduced.

We may conclude that fossil placers probably did exist and that they were enriched by Tertiary veins.

SEARCH FOR NEW ORE BODIES

The conclusions reached regarding the nature and origin of the Homestake ore body can be applied directly in the development of the ore body and in the search for new ore bodies. The approximate position of the ore-bearing beds, those favorable to ores, can be determined by structural and stratigraphic studies on the surface and underground. Drilling and workings should be directed according to such studies.

The influence of porphyry as a possible enricher of the pre-Cambrian ore should be a subject of continued study.

To summarize the geologic factors that favorably affect the location of ore:

1. The metamorphic carbonate beds that contain cummingtonite have so far proved the best ore carriers. They are overlain by barren quartzites and schists. These overlying beds were unfavor-

able to ore deposition and may have impounded solutions, thus favoring concentration of ore in the immediately underlying carbonate series.

2. Close folding, with the consequent thickening of the favorable beds, produces a large body of replaceable rock.

3. Shearing favored the deposition of abundant sulphides, and abundant sulphides generally accompany ore.

4. Enrichment is probably greatest near the Tertiary porphyry.

INDEX