DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Professional Paper 97

GEOLOGY AND ORE DEPOSITS OF THE MACKAY REGION, IDAHO

BY

JOSEPH B. UMPLEBY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

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

CONTENTS.

ILLUSTRATIONS.

OUTLINE OF PRINCIPAL RESULTS.

The Mackay region, in southeastern Idaho north of Snake River, is well known to geographers through Big Lost and Little Lost rivers, which sink from sight near the margin of the Snake River plains, and to mining men through the White Knob (now the Empire) copper deposits.

Most of the ore deposits of the region were discovered by the army of prospectors that invaded eastern Idaho about 1880 and within a few years passed on to other regions. The wave of mining activity in the northern part of the area rose and fell with the Nicholia enterprise, active during the decade preceding 1890, and the history of the Muldoon district is similarly related to that of the Wood River camps, which attained the acme of their prosperity during about the same period. The copper deposits near Mackay, though known to these early prospectors, have been most actively exploited since 1900. The total production of the region is about $3,750,000, of which $2,300,000 has come from copper, $100,000 from gold, $700,000 from silver, and the remainder from lead.

The region comprises a high, mountainous area traversed in a northwest course by three deep valleys, which merge into the Snake River plains on the southeast. The elevations range from 5,000 to 12,000 feet above sea level, the relief being commonly about 5,000 feet. Near the close of the Eocene epoch the area was elevated from a lowland of moderate relief to a plateau about 12,000 feet high, which has since been intricately and deeply dissected by erosion. During Pleistocene time the highland areas were covered by glaciers and many of their beauties are due to the diverse activities of moving ice.

The rock formations of the region include more than 20,000 feet of strata ranging in age from Algonkian to Pennsylvanian. The Algonkian rocks comprise intensely metamorphosed schists, slates, and quartzites, exposed only in the Lemhi Range. Overlying these unconformably are Cambrian (?) quartzites, Ordovician quartzite and dolomite, Devonian dolomite, limestone, and calcareous shale, Mississippian limestone, and Pennsylvanian limestone and calcareous sandstone and shale. The Mesozoic era is not represented by stratified rocks, but intrusions of granite invaded the older strata in late Cretaceous or early Eocene time. In the Miocene epoch of the Tertiary period vast volumes of andesitic and related lavas flooded deep valleys that had developed after the elevation of the Eocene surface, which, as its remnants show, was of gentle topographic form; and behind these flows lakes formed, in which Miocene sediments accumulated. After the lapse of a long time, during which erosion was the dominant process, igneous activity again became rife and extensive sheets of basalt were poured forth upon the Snake River plains.

Three major epochs of deformation are recorded in the rocks of the region. Great movements in the earth's crust near the close of the Algonkian period crushed and crumpled the pre-Cambrian rocks to an extent far greater than that of the Paleozoic beds. Throughout the Paleozoic era there were no movements of sufficient extent to cause marked angular unconformity of the strata, but after its close the beds were thrown into folds that show average dips of about 45°. Still later compressional stresses are recorded in the local tilting of Miocene beds to angles of 35°, although in general the post-Eocene movements have resulted in broad crustal warpings rather than sharp folding.

The principal ore deposits of the region are contact-metamorphic replacement deposits and lead-silver veins and tabular replacements. Silver-gold veins were worked at one time and tungsten has recently been reported.

Two periods of mineralization are represented, one following closely the granitic invasion and the other subsequent to the eruptions of andesitic and related lavas.

The contact deposits, now the most productive in the region, are of particular scientific interest because their relations show that the granite magma supplied vast quantities of iron, alumina, and silica to the contact rocks as well as the constituents of the sulphide minerals, and that it did so after the outer few hundred feet of the magma had solidified. They also indicate that there were two stages of metamorphism, one coincident with intrusion and one subsequent to the fracturing of a solid magma shell; of the second stage there can be no reasonable doubt.

The lead-silver deposits of the Dome district include considerable bodies of plumbiferous quartzite, a type of lead ore which, so far as the writer is aware, has not heretofore been described. The impregnation of the quartzite by lead was accompanied by the extensive introduction of some manganese-bearing mineral, probably siderite. These bodies of ore and the veins connected with them are now the principal source of lead in the area.

The deposits of the Era and Lava Creek districts, which have not been actively exploited for years, belong to a rare group of late Tertiary veins in which base metals occur in considerable amounts. A notable feature of the deposits is the occurrence in them of wurtzite, the hexagonal form of zinc sulphide. This mineral has been believed to form only in an acidic environment, and in all deposits, with one or two exceptions, it has been described as a product of descending solutions. Here, however, it is unmistakably a primary mineral, and all other observed features of the deposits, except possibly a small amount of barite, suggest primary acidic solutions.

Sixty-seven mineral species are recognized in the ores of the Mackay region, one of them, custerite, being new to science.

The region comprises eleven mining districts, at least three of which are of more than ordinary promise to the prospector, and it is hoped that they will be more carefully searched for outcrops of ore. Under the heading "Practical conclusions and suggestions to the prospector" observations are made which it is believed will assist in leading to new discoveries. (See p. 91.)

GEOLOGY AND ORE DEPOSITS OF THE MACKAY REGION, IDAHO.

By JOSEPH B. UMPLEBY.

INTRODUCTION.

SCOPE OF THE REPORT.

This report embodies the results of a three-months' reconnaissance made by the writer, with the aid of one nontechnical assistant, of about 3,200 square miles in southeastern Idaho north of Snake River. (See fig. 1.) A base map on the scale of 1 : 250,000, with 1,000-foot contour intervals, was prepared, section corners along the larger valleys being used to establish base lines, from which control was spread, by plane-table triangulation, into the high mountainous areas. Only in the southwestern part of the region was it necessary to carry the control more than 10 or 15 miles from section corners. It is believed that for the major features of most of the region, therefore, the map presents about the same order of accuracy as the General Land Office plats of agricultural lands. Altitudes were determined by aneroid readings and by vertical angles taken from points in the larger valleys.

Six geologic units were mapped—Algonkian schists, Paleozoic beds, late Cretaceous or early Eocene granite and granite porphyry, Miocene andesites and rhyolites, Snake River basalt (probably chiefly Pliocene), and Quaternary alluvium. Their contacts, where definitely known, are represented on the map by solid lines, but where the boundaries were not traced or are concealed the division lines on the map are dotted. (See Pl. I, in pocket.)

Special topographic and geologic maps were prepared of a part of the Alder Creek district and of a part of the Dome district, both on a scale of 1 to 12,000. The study in these two districts may be classed as detailed reconnaissance; that of the others as rapid reconnaissance.

Paleozoic rocks are predominant in the area and include thick formations, ranging in age from probably Cambrian to early Pennsylvanian, inclusive, but they have been so greatly disturbed by crustal movements that to map them, even approximately, would require several seasons. So complex are the structural relations that a complete section was not obtained, although several partial sections, which should be of value in future work, are described.

The physiographic history of the region is also difficult to decipher, but its major features are believed to be understood, and it is thought that future work will supplement rather than seriously change the conceptions here presented.

FIELD WORK AND ACKNOWLEDGMENTS.

Field work began June 29, 1912, and continued until October 10 of the same year, except for the interval from August 28 to September 22, which was spent in a preliminary examination of the Hailey and Sawtooth quadrangles, west of the Mackay district. In June, 1913, while the writer was outfitting for work in areas farther west, he spent three days in reviewing certain important features of the copper deposits near Mackay. Again, in September, 1913, he spent three days in collecting fossils east of Mackay; also, in the fall of 1913 E. H. Finch, assistant to the writer during that year, spent three days in collecting the notes on the Muldoon district, herein presented.

During the general reconnaissance C. H. Gray rendered valuable assistance in preparing the topographic maps, nearly all the triangulation and most of the topography being the result of his work. During the writer's last visit to the area G. H. Girty, one of the paleontologists of the Geological Survey, accompanied him for

three days in collecting fossils and studying the Paleozoic stratigraphy east of Mackay. The writer is also indebted to the mining men of the region for their courteous cooperation throughout the investigation. Particularly does he desire to express his appreciation of the generous assistance rendered by Messrs. Frank M. Leland and Ralph R. Osborn, of the Empire Copper Co., and Messrs. Harry K. Knight and Charles A. Peet, of the Wilbert Mining Co. Mr. C. I. Huddle, supervisor of the Lemhi National Forest, furthered the work by innumerable courtesies, both personal and official.

The writer is indebted to George Steiger, Chase Palmer, W. C. Wheeler, W. T. Schaller, and R. C. Wells for chemical determinations; to G. H. Girty, Edwin Kirk, and E. M. Kindle for the determination of fossils; and to his several colleagues in the Geological Survey's section of metalliferous deposits, particularly

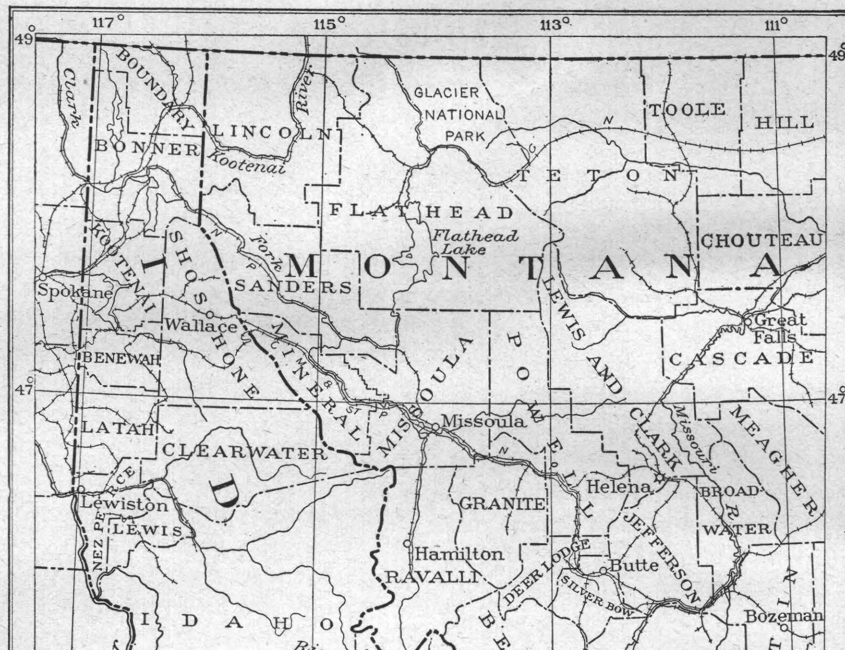


FIGURE 1.—Index map showing location of Mackay region, Idaho.

Adolph Knopf, with whom he freely discussed the problems of the contact deposits. Grateful acknowledgment is made for kindly criticism and suggestions by Waldemar Lindgren, under whose supervision the work was begun, and by F. L. Ransome, who succeeded Mr. Lindgren as geologist in charge of the section of metalliferous deposits.

LITERATURE.

The literature on the geography, geology, and ore deposits of the area herein described is very scant, although adjacent regions have been the subject of reconnaissance studies. The principal map of the area is that compiled by the Forest Service and known as the Lemhi folio. It was compiled by H. S. Meekham in 1909 and incorporates all information available at that time. The only additional information consists of a few township plats of more recent date and unpublished sketches in the local Forest Service office.

In 1907 the copper deposits near Mackay were described by J. F. Kemp and C. G. Gunther, and in several of the annual reports of the State inspector of mines mention is made of different deposits in the region.

The following is a list of the more important publications and articles on this and near-by areas:

Emmons, S. F., Livingston to the Snake Plains: Cong. géol. internat., 5th sess., Compt. rend., pp. 367–374, 1893. Describes the geology along the route of travel and the geologic history of the Snake River plains.

Eldridge, G. H., A geologic reconnaissance across Idaho: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, pp. 211–276, 1895. Describes the geologic features and some of the ore deposits along a route from Boise to Salmon and thence by way of Challis to Hailey and west to Boise.

Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, pp. 75–256, 1900. Describes the character and occurrence of the igneous and sedimentary rocks and the occurrence and nature of the ore deposits of a large area lying west of the Mackay region.

Russell, I. C., Geology and water resources of the Snake River plains of Idaho: U. S. Geol. Survey Bull. 199, 192 pp., 1902. Discusses the topography, the basement series of rocks, the lacustrine deposits, the lava flows, and the water resources of the area. Describes many interesting features along the southeast side of the Mackay region.

Kemp, J. F., and Gunther, C. G., The White Knob copper deposits, Mackay, Idaho: Am. Inst. Min. Eng. Trans., vol. 38, pp. 269–296, 1908 (Am. Inst. Min. Eng. Bimonthly Bull. 14, pp. 301–328, March, 1907). Describes the copper deposits near Mackay and discusses their origin. Believes that the "uprising gases and vapors passing through a molten or viscous mass have at least established the lines for the development of the garnet, diopside, and other minerals" that occur within the granite porphyry mass.

Stephens, H. J., The Copper Handbook, vol. 8, pp. 664–665, 1426–1428, Houghton, Mich., 1908: Outlines the history of the several White Knob companies which preceded the Empire Copper Co. in the Alder Creek district and gives considerable information concerning the equipment of the Empire mine and the occurrence and tenor of the ore.

Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, 182 pp., 23 pls., 1913. Describes physiography, general geology, and ore deposits of the county. In the final chapter the nineteen mining districts are treated separately.

Umpleby, J. B., Some ore deposits in northwestern Custer County, Idaho: U. S. Geol. Survey Bull. 539, 104 pp., 10 pls., 1913. Describes the physiography, geology, and ore deposits of the Loon Creek, Yankee Fork, and Bay Horse districts.

MINING HISTORY AND PRODUCTION.

Mining activity in the Mackay region began soon after the discovery, in 1880, of the rich lead-silver deposits in the Nicholia district, which is a few miles north of this region. Inspired by the profitable exploitation of those deposits prospectors spread into the surrounding country, searching for lead-silver ore with a thoroughness that has never since been equaled in the region. Few of the deposits now known were early unknown to them. Small shipments of ore were made to the Nicholia smelter from the Skull Canyon, Birch Creek, Dome, Era, and Lava Creek districts, but with the abandonment of the Nicholia enterprise, about 1890, mining activity in the northern part of the region ceased. The history of the Muldoon district, to the south, is similarly bound up with that of the Wood River camps, which attained the acme of their prosperity late in the eighties of the last century.

The copper deposits near Mackay and Kaufman were discovered during this early period of mining activity but were not exploited until more than a decade later, when the mining industry of the region to some extent revived. Since 1900 the history of the mine now owned by the Empire Copper Co. has been essentially the history of mining in the region. Operations on this group of claims began on a large scale in 1901 with the building of a smelter with two 125-ton blast furnaces at Mackay. The succession of White Knob companies which owned this property during the next five years is notorious in the annals of mining, each being a drain on the investing public and a failure more disastrous than the one preceding it. After an expenditure of about $3,000,000 without a cent of profit the enterprise passed into the hands of the Empire Copper Co., an entirely new organization, which has operated the mine on a leasing system at a noteworthy profit. The deceit and mismanagement that characterized its early history have been a serious detriment to the development of the mineral resources of the region, but its present management is conservative, and the company is encouraging the local industry in every legitimate way.

Recently the profitable exploitation of the lead-silver deposits of the Wilbert mine has given impetus to this branch of the industry. This mine, formerly known as the Daisy Black, made its first production in 1906, but not until the erection of a 100-ton concentrating mill in the fall of 1911 was it actively exploited. During 1912 and 1913 the mill was operated most of the time, but in the first half of 1914, owing to the low price of lead, it was closed, although development of the ore bodies proceeded.

The production of the Mackay region can be only roughly estimated, as a considerable part of its output was made during the early period of activity, of which there is no satisfactory record. Even in recent statistical reports the county is the unit, and as this region includes parts of several counties but not all of any one county it is impossible to assemble accurate figures for the region from these reports. The total production of the region up to January 1, 1914, was probably not far from $3,750,000, of which $2,300,000 came from copper, $100,000 from gold, $700,000 from silver, and the remainder from lead. The Alder Creek and Dome districts, for which the record of production is more accurate than for the others, produced approximately $2,500,000 and $500,000, respectively, to January 1, 1914. Next follows the Era district, with an estimated production of $300,000; the Muldoon district, with $200,000; Copper Basin, $90,000; Birch Creek and Skull Canyon, each about $65,000; and Lead Belt district, with $25,000.

GEOGRAPHY.

SITUATION AND ACCESS.

The Mackay region as herein defined is in southeastern Idaho, north of Snake River, and includes parts of Custer, Blaine, Lemhi, Jefferson, Fremont, and Bingham counties. Mackay, the principal settlement in the region, is centrally situated and is reached from Blackfoot by a 96-mile branch of the Oregon Short Line Railroad. The railroad leads up the broad valley of Big Lost River past the settlements of Powell, Arco, Moore, Darlington, and Leslie. Stages run from Arco three times a week to the upper valley of Little Lost River and once a week to Martin in the Lava Creek district. A stage line, with weekly service, connects Darlington with Grouse post office. From Mackay stages run daily except Sunday west to Challis, the county seat of Custer County. Mail is carried into the Birch Creek valley by triweekly stage from Dubois, on the Butte branch of the Oregon Short Line, and until recently was taken into the Muldoon district from Hailey, the county seat of Blaine County.

SETTLEMENTS.

Mackay, which has a population of perhaps 1,500, is the largest settlement in the region and is the supply point for its central and northwestern parts. Smaller settlements, most of them consisting only of a general store, a post office, a blacksmith shop, and a few residences, are distributed along the large valleys. There are post offices in the Birch Creek valley at Kaufman; in the Little Lost River valley at Howe, Bernice, and Clyde; in the Big Lost River valley at Mackay, Arco, Moore, Darlington, Leslie, and Dickey; in Antelope Valley at Grouse; and in the Lava Creek district at Martin. Arco, which has a population of perhaps 500, is, next to Mackay, the principal settlement in the region.

The valley of Big Lost River, a broad and fertile intermontane depression, is rather thickly settled, and perhaps most of the available land is under irrigation. In the valleys of Little Lost River and Birch Creek, however, a smaller proportion of the land is cultivated, because of the inadequate supply of water. An attempt recently made to irrigate a large tract of land about the mouth of Little Lost River has met with only moderate success because of leakage from the canals, which traverse many miles of gravel terraces; and a similar attempt to put water on large tracts in the vicinity of Powell and Arco has been a total failure and financially disastrous to many of the settlers, who were required to make heavy initial payments before the canals were completed. In Antelope Valley the supply of water is more abundant and much of the land is under cultivation.

LINES OF TRAVEL.

The principal lines of travel within the region follow the margin of the Snake River plains and the valleys of Birch Creek, Little Lost River, Big Lost River, and Antelope Creek. There are also three excellent wagon roads across the Lost River Range—one through the canyons of Pass and Wet creeks, east of Mackay; another over Double Springs Pass, north of Dickey; and a third across the south end of the range, north of Arco. There is also a passable road leading from the valley of Big Lost River up Lehman Creek over the summit into Copper Basin, and another from Antelope Valley across to Era and Martin. Trails and wood roads extend into the mountainous parts of the area at many places, but large portions of it can be traversed only on foot and with extreme difficulty.

CLIMATE AND LIFE.

The Mackay region has a great range in climatic conditions coordinate with its great range in altitude. From high tracts deeply covered with snow throughout a long winter season the climatic transition is gradual to the lowlands, where snow seldom persists for more than a few weeks at a time. The open season is from May to October, inclusive, although May is a rainy month and October has usually one or more snowstorms. On the north slopes of the higher peaks snow lies throughout the summer, forming a striking reminder of the larger perennial fields of snow and ice which, in late geologic time, carved and molded the upland topography.

The area as a whole is one of abundant precipitation, and most of the canyons are occupied by streams which live throughout the year, though they sink beneath the surface beyond the canyons. After uniting to form the major streams, they approach the Snake River plains. The major valleys are floored with loose gravels covered thickly with fertile soil, through which, however, the water sinks, making its conveyance through artificial canals very difficult and not feasible for long distances. For this reason the vast tracts of fertile basalt soil along the margin of the Snake River plains in large part lie unreclaimed and support a scrubby growth of sagebrush where otherwise any of the crops of this latitude would flourish. Recently dry farming with winter fallowing and crops in alternate years has been attempted in these areas and gives some promise of success.

The principal industry of the region is stock raising, and the crops consist mainly of hay and grain for the winter feeding of the thousands of sheep and cattle which range widely in the open seasons. Mining is of local importance in the area and supports a small part of the population. Lumbering has not been developed beyond the requirements of the moderate local market.

The mountainous parts of the Mackay region support many different kinds of wild game, although game is less abundant than in the more inaccessible country to the west. Many deer, coyotes, several mountain sheep, goats, bobcats, and an occasional bear, wolf, and lynx are killed each year within the region. Several bands of antelope roam the uninhabited parts of the lower country, but these animals and beavers are protected by State laws. Grouse and sage hens are abundant, and great numbers of ducks frequent the lakes near Dickey.

A thick forest growth covers most of the northern slopes between the altitudes of 6,500 and 9,500 feet, but the vegetation on the southern slopes is principally grasses and scrubby sagebrush. The trees are predominantly of the evergreen variety and include the Douglas fir (*Pseudotsuga taxifolia*), lodgepole pine (*Pinus contorta*), Englemann spruce (*Picea engelmanni*), limber pine (*Pinus flexilis*), alpine fir (*Abies lasiocarpa*), and juniper (*Juniperus*). Mountain mahogany (*Cercocarpus ledifolius*) is locally abundant and is of great value to the residents for firewood. The most valuable tree of the forest is the Douglas fir, which supplies the lumber for local consumption. It grows in fairly pure stands between altitudes of 6,500 and 8,000 feet, and the individuals average perhaps 16 to 18 inches in diameter. Above 8,000 feet lodgepole pine occurs with the fir in mixture and as separate stands. The limber pine and Douglas fir are intermixed with alpine fir at altitudes of 9,000 to 9,500 feet, above which the mountains are bare of trees. Below 6,500 feet and on southern slopes up to higher levels "the ground cover is made up of sagebrush and kindred shrubbery, drought-resistant species, as well as early maturing grasses and herbaceous plants." [1]

PHYSIOGRAPHY.

EXISTING TOPOGRAPHY.

GENERAL FEATURES.

The Mackay region is a high, mountainous area, traversed in a northwesterly course by three deep valleys which open on the southeast into the Snake River plains. The altitudes range from 5,000 to more than 12,000 feet above sea level, but the common relief is about 5,000 feet. The area constitutes a border portion of the great interior plateau of Idaho, and although the old erosion surface which is conspicuous in that area is not clearly discernible here, yet it is believed that the rough accordance in summit levels of the upland tracts is a feature inherited from a surface coincident with the plateau. The two areas are separated only by the deep, narrow canyon of Salmon River, which flows northward west of the area represented by the map (Pl. I, in pocket).

The drainage of the region presents many interesting features. In the three major valleys which traverse it streams flow in opposite directions. Birch Creek and Little and Big Lost rivers debouch upon the Snake River plains, there to disappear beneath the lava surface; and in the opposite ends of the same intermontane depressions, mostly beyond the limits of the area shown on the map (Pl. I), flow Lemhi and Pahsimeroi rivers and Warm Spring Creek, tributary to Salmon River.

VALLEYS.

The major valleys are deep, flat-floored depressions bordered by rugged slopes and in places by precipitous cliffs. Throughout their courses they are of remarkably uniform width and in general follow the strike of the formations that constitute the adjacent uplands. To this, however, there are a few notable exceptions. The great valley of Snake River, floored with sheets of basalt over an estimated area of 20,000 square miles, traverses almost at right angles the prevailing structural axes of the region. Similarly, the valley of Antelope Creek, a large tributary of Big Lost River near Darlington, and the upper valley of Big Lost River itself (Pl. II, *B*) cut directly across the strike of the formations. Other noteworthy features of the valleys are the local extensions of the valley floors back into the mountain masses in places where no streams of importance flow and the projection of the uplands into the valleys. A striking instance of a reentrant valley occurs northeast of Arco, where an embayment floored with broad alluvial fans but containing no permanent stream extends 7 miles into the Lost River Range. A similar embayment is drained by the upper waters of Wet Creek, on the north side of the range. The most conspicuous examples of capes or peninsulas from the uplands into the valleys occur west of Darlington and south of the Wilbert mine. The features south of the Wilbert mine may be due to a great landslide about which alluvial fans have formed, concealing the base except next to the Lemhi Range, but those west of Darlington present no internal suggestion of such an origin.

Copper Basin, at the headwaters of the East Fork of Big Lost River, is a large intermontane depression 8,000 feet above sea level. It is about 10 miles long and widens headward from 1 mile to about 6 miles in the vicinity of the Reed & Davidson mine. It drains westward, and in that direction merges into a narrow canyon which continues to the main valley of Big Lost River. There is a similar but smaller highland basin about the head of Pass Creek, in the Lost River Range.

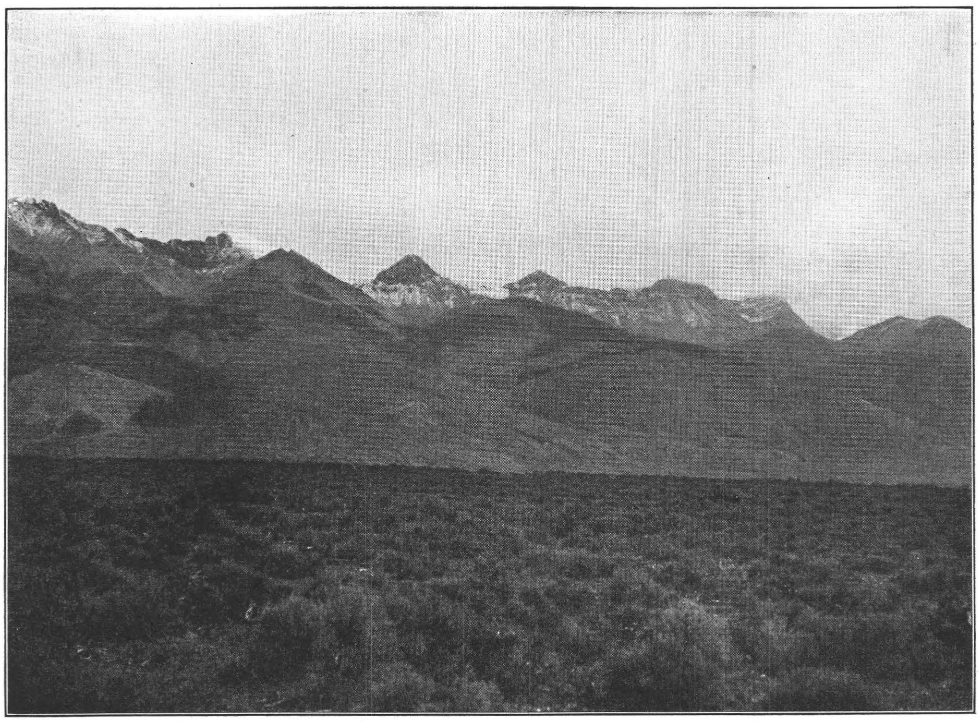
The divide which separates the drainage of Birch Creek from that of Lemhi River, a stream flowing in the opposite direction in the same general depression, is imperceptible.[2] The divides between Little Lost and Pahsimeroi rivers and Big Lost River and Warm Spring Creek are more pronounced, although neither is higher than 7,200 feet, the altitude of the Lemhi-Birch divide.

UPLANDS.

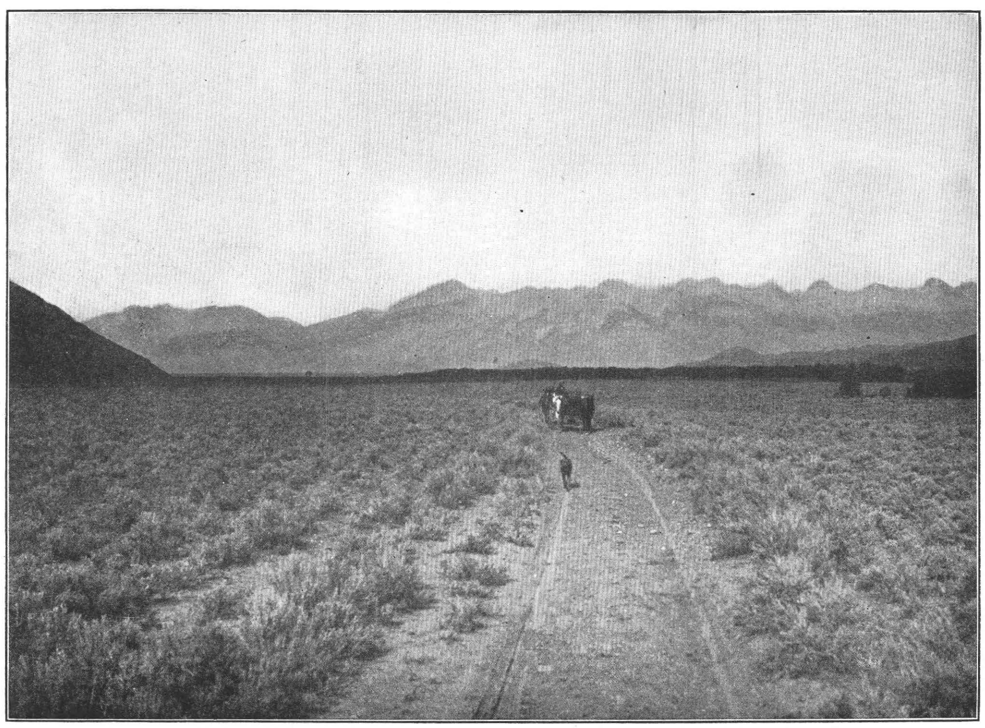
The uplands of the region may be grouped as three well-defined ranges and one mountainous area of irregular outline. Each of them connects on the west, except for the deep, narrow

[1] The above notes on the forest growth are taken principally from a manuscript in the files of the Forest Service, entitled "General silvical report, Lemhi National Forest," by A. L. Bower, Jan. 13, 1912.

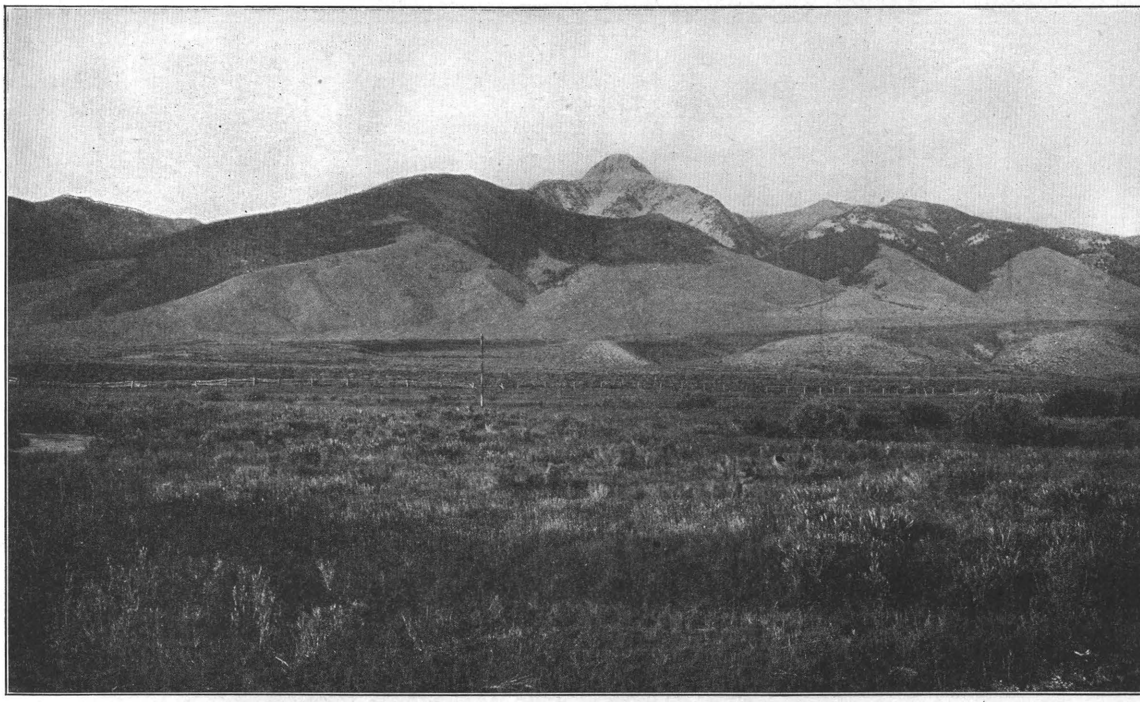
[2] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, pl. 1, 1913.



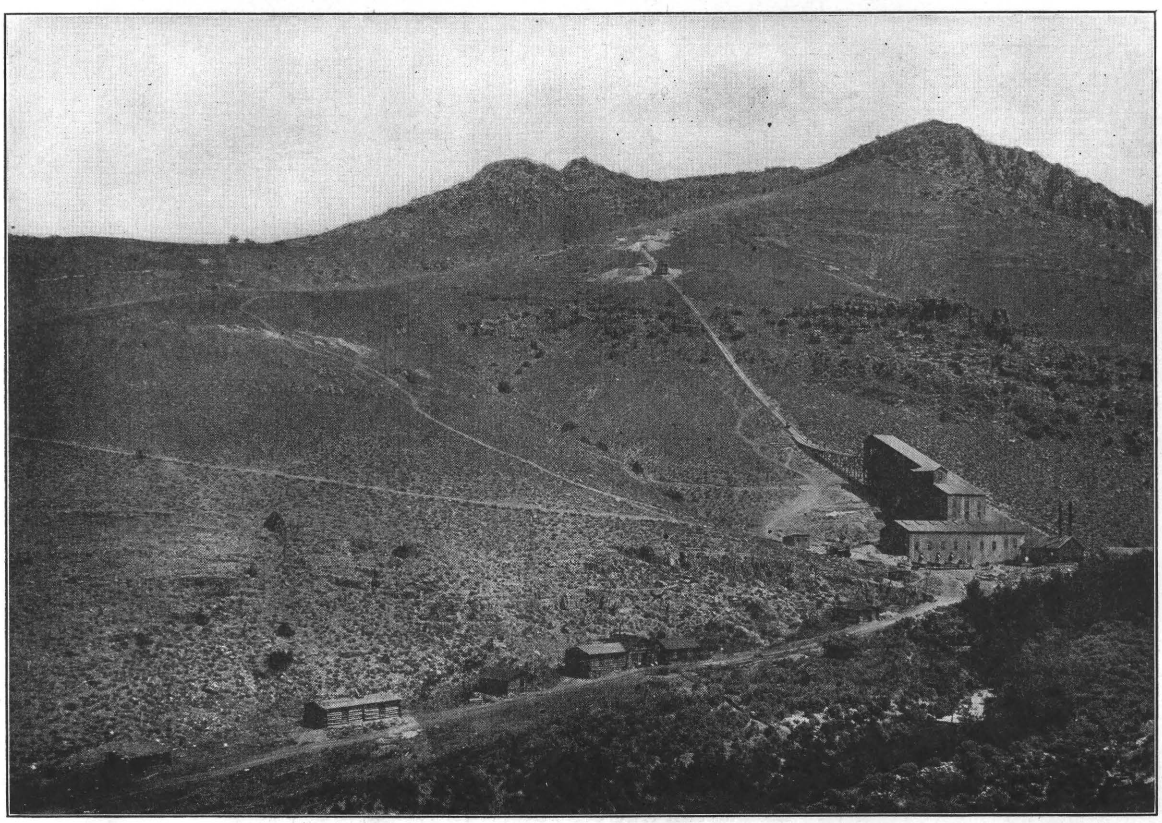
A. LOST RIVER RANGE ABOVE MACKAY, IDAHO.



B. LOST RIVER VALLEY FROM A POINT 12 MILES WEST OF CHILLY, IDAHO.
Looking east toward the Lost River Range.



A. PYRAMID PEAK, LEMHI RANGE, AS SEEN FROM KAUFMAN, IDAHO.



B. WILBERT MINE AND MILL, DOME DISTRICT, IDAHO.

canyon of Salmon River, with the great interior plateau of Idaho, with which the summit topography is correlated.

The range northeast of the Birch Creek valley is a southward spur from the Beaverhead Mountains, which form the continental divide from the Bitterroot Range southeastward to the low pass at Monida. It lies between the valleys of Medicine Lodge and Birch creeks and is probably a sufficiently distinct topographic unit to warrant specific designation, but as only one side of it has been mapped it is, perhaps, best to await the results of subsequent work before suggesting a name. Along its western face smooth grass-covered slopes, broken here and there by precipitous cliffs, rise to the summit, 9,000 to 9,500 feet in altitude. The range is carved from steeply folded limestone, slate, and quartzite beds of Paleozoic age.

Between the broad valleys of Birch Creek and Little Lost River a narrow, rugged range rises to heights of 10,000 or 11,000 feet. On the north, without being broken by a single pass lower than 9,300 feet, it continues as the Lemhi Range between the valleys of Lemhi and Pahsimeroi rivers. The southern part (Pl. III, *A*) has been called the Little Lost River Mountains and the northern part the Lemhi Range, but as it has now been mapped on both sides throughout its extent[1] without revealing any logical basis for the division, it is proposed to use the term Lemhi Range for the entire mass from the Snake River plains on the southeast to the canyon of Salmon River on the northwest. This range, which is far more rugged than that to the east, is carved from Paleozoic quartzites, dolomites, and limestones, and, locally, from Algonkian schists, slates, and quartzites.

The most rugged and forbidding of the mountain units of the region, however, is that between the valleys of Little Lost and Big Lost rivers. (See Pl. II, *A*.) From the Big Lost River valley the range rises by precipitous slopes, many of which can not be scaled, to a height of 10,500 to 11,000 feet, but on the northeast side the slopes are less rough and afford grazing for sheep and cattle. Narrow box canyons that have been cut across steeply folded, in many places vertical, beds of limestone and dolomite extend into the range from the southwest and locally head against long valleys from the opposite side, thus affording low divides easy of passage. Pass Creek summit and Double Springs Pass, at altitudes of 7,500 and 8,200 feet, respectively, are so situated. There is also a low pass northeast of Arco. The range, except for these three passes, extends as an unbroken unit from the Snake River plains northwestward about 75 miles to the canyon of Salmon River at a point north of Challis, the county seat of Custer County. In its southern part it separates the valleys of Little and Big Lost rivers; on the north it rises between those of Pahsimeroi River and Warm Spring Creek. The name Lost River Range is here proposed for this entire mountain unit, the northern part of which was formerly known as the Pahsimeroi Mountains and the southern part as the Lost River Mountains. The name Pahsimeroi Mountains, first applied in 1891, is retained for that portion of the range which lies between the headwaters of the Pahsimeroi and the valley of Big Lost River, because many biologic species have been referred to it.[2] As seen from the valley of Pahsimeroi River, these mountains seem to be a separate "group of lofty, rugged, snow-marbled peaks, arranged in the form of a double or triple amphitheater," but more extended observation shows them to be merely a local feature of the continuous mass to which the name Lost River Range is here applied.

The fourth mountain unit lies south of Big Lost River. Farther west its central divide, which separates waters flowing north into Big Lost River and south into Little Wood River, merges into the well-defined Sawtooth Range, but within the Mackay region there is no axis of pronounced development. Copper Basin, in which rises the East Fork of Big Lost River, lies well within this mountain area, and the valleys of Antelope Creek and its tributaries extend far into it. That portion of the mountains which lies between East Fork and the North Fork of Antelope Creek on the southwest and Big Lost River on the northeast might be considered a separate range, but there is at present nothing to be gained by specific designation. In this report this entire tract is simply called the mountainous area south of

[1] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, pl. 1, 1913.

[2] Merriam, C. H., Results of a biological reconnaissance in south-central Idaho: U. S. Dept. Agr. Div. Ornithology and Mammalogy Bull. 5, p. 14, 1891.

Mackay. The older rocks in it are Paleozoic beds cut by batholithic masses of granite, and these are concealed in many places by andesites and related lavas and tuffs. The summits rise to about 10,000 feet above sea level.

SNAKE RIVER PLAINS.

Along the southeast border of the Mackay region the mountains break off abruptly and the valleys expand as they unite with the great basalt-flooded valley that constitutes the Snake River plains. As seen from a point near Arco, the level sagebrush-covered surface extends east and south to the horizon, the only relief from the monotony being afforded by Big, Middle, and East buttes, which rise several hundred feet above the basalt surface. The elevation of the Big Butte above the plains is said by Russell to be 2,350 feet; the other buttes are lower.

During the present reconnaissance these buttes were not visited, and but few observations of the phenomena of the plains were made. Russell,[1] however, describes this portion of the region so vividly, as he saw it from the summit of Big Butte, that an extract from his paper will give an adequate idea of the western margin of the plains, the part adjacent to the Mackay region.

On reaching the summit of Big Butte on a clear day there is a far-reaching view in all directions, and much of the history of the Snake River plains may be easily read in the splendid panorama. * * *

The mountains to the east are fully 50 miles distant, and the nearest peaks to the west are from 30 to 40 miles away; to the southwest and northeast the flat plain extends indefinitely, and no bordering shore is in sight. In spite of their remoteness, the Lost River Mountains to the west are clearly and even sharply defined. The upward sweep of alluvial fans can be easily traced to where they narrow at the mouths of strongly cut gorges. Above their summits are the outlines of bare crags, where angular rocks form bold convex curves, which replace concave curves due to stream deposition on the lower slopes. Still higher is a dark band of forest which encircles the mountain like a shadowy wreath. Far above the timber line are bare serrate peaks, all of them light gray and suggesting the presence of limestone or quartzite, except the highest pinnacles of all, which gleam silver white. A recent storm, which brought light showers to the plains, covered the higher mountains with snow. Roads on the plain appear as fine lines radiating from the spring at the northern base of the mountain. Each curve in the yellow line leading west can be clearly followed to Arco, 24 miles distant, where clumps of bushes and a few houses tell of the presence of water. Other clumps of bushes and here and there a field of alfalfa, a rectangular patch of green on the gray expanse, reveal the curves of Big Lost River as it flows through the plain, bends northward, and in winter maintains its existence for about 50 miles to where it spreads out in a small lake. To the northeast, and seemingly close at hand, although 15 and 20 miles distant, Middle and East buttes rise abruptly. The nearer butte is black; its sloping surface is inclined to the southeast, in conformity with the dip of the hard-rock layers of which it is composed. The western border is abrupt at the summit, but below it has much more gently inclined lines, due to talus slopes. East Butte is white, rises sharply on all sides, is without conspicuous talus slopes, and terminates above in two sharp angular peaks, between which there is a smooth saddle-shaped depression, suggestive of a broken crater. * * * Still farther to the northeast and, as one is surprised to learn on referring to a map, 46 miles away, the outlines of Market Lake craters are clearly visible. Their characteristic conical forms, with flat summits, leave no doubt that they are extinct volcanoes. From personal examination I know they are tuff cones with craters in their tops. When the eye has become adjusted to the novel conditions it perceives that the vast plain is not absolutely flat and featureless; and as evening approaches and a strong side light causes even small elevations to cast shadows, many cone-shaped prominences rise from the previously flat surface. That these are extinct volcanoes is clearly shown by an example, only 3 or 4 miles distant to the southeast, from which a black stream of lava with a bare, rough surface, evidently of recent date, extends northward and expands into a belt a mile or more wide before terminating. This recent addition to the rocks of the plains resembles a great withered and blackened leaf, with its petiole still attached, laid on the flat surface. Another black lava stream, starting from an elevation a few miles to the eastward, also flowed northward and expanded into a leaf-like form several square miles in area. These two recent lava streams indicate that the plain of which they form a part has not been produced by a single vast outpouring of molten rock but is in reality highly compound and consists of many widely expanded and overlapping lava sheets. A small elevation, the summit of a low cone with an immensely expanded base, occurs about 8 miles to the south. It is similar to those from which lava was recently poured out but is much older. The lava has evidently flowed away from a small opening in all directions so as to form a cone, with a diameter at the base of certainly 8 and probably as much as 10 miles. When this old volcano is seen in profile from the surface of the surrounding plain it presents the appearance of another similar cone * * * about 15 miles to the west of Big Butte. The cone just referred to, together with two companions, is also in sight from the summit of Big Butte, and still others of similar shape, all broad, low cones, usually with flat summits, may likewise be distinguished. To the west * * * are the Cinder Buttes, among which a score or more volcanic cones are known to exist. Not including the Cinder Butte, or East Butte, about 20 craters can be counted on the broad plain, and still others occur which can not be readily recognized from a distance. Evidently a very large portion of the

[1] Russell, I. C., Geology and water resources of the Snake River plains of Idaho: U. S. Geol. Survey Bull. 199, pp. 36-38, 1902.

lava occurring as a surface covering on the Snake River plains came from small and inconspicuous craters, many of which have escaped burial by later eruptions and still exist as elevations.

BIG LOST AND LITTLE LOST RIVERS.

Big Lost and Little Lost rivers and Birch Creek emerge from their mountain valleys as streams of considerable size, but their waters sink beneath the surface soon after reaching the Snake River plains, and not even during the spring freshets do they cross its surface and join Snake River. The lavas next to the mountains are somewhat lower than those farther out, and on reaching them the streams bend their courses in conformity to the topography, Big Lost River flowing northward in times of high water to a point near the mouth of the Little Lost River valley and Birch Creek turning southward to the same place. Here there are a number of shallow silted basins which in the spring are covered by an ephemeral sheet of water that is gradually reduced to a number of smaller bodies as the season progresses and that finally disappears.

Along the upper courses of these streams there are also noteworthy "sinks," or places where the water sinks into the stream bed. These are most clearly discernible late in the summer. A large sink occurs near "the narrows" a few miles above Mackay. In the vicinity of Darlington a considerable strip of the river's bed is dry at times, but a short distance downstream the river again attains nearly its full size and flows to a point above Arco; here much of the water again sinks, but it reappears in the vicinity of the town only to disappear entirely a few miles below. Similar sinks said to occur along the course of Little Lost River and Birch Creek were not examined by the writer.

PHYSIOGRAPHIC DEVELOPMENT.

GENERAL FEATURES.

The Mackay region may be described briefly as a highland area of profoundly folded rocks, traversed by a complex system of valleys, most of which lie athwart the structural axes. Some of the valleys are clearly older than the present drainage cycle; for instance, the valley extending northward from Arco and devoid of any stream, the pronounced depression of Copper Basin, whose outlet is through a narrow canyon, and the basin near Pass Creek summit, which is similarly drained. Each of these valleys lies within a lava belt. That near Arco extends northward and is probably an old erosion valley locally flooded with lavas. Copper Basin is a depression in a lava belt which extends southeastward from the vicinity of Challis and joins the Snake River plains at Martin. The Pass Creek basin is near the head of a lava belt which extends across the Lost River Range and along its eastern flank to a point beyond the limits of the area mapped, where its identity is lost beneath the alluvial fans that form the floor of the Pahsimeroi Valley. North of the Pass Creek summit is a considerable area of lacustrine deposits, which are bordered on the south, west, and northwest by the lava rocks. These beds represent an inclosed basin that existed within the lava area during the later stages of eruption, as is shown by thin sheets of lava interbedded with the stratified rocks northeast of Warren Peak. Copper Basin may also have existed as such during the later stages of lava eruption and may merely represent part of a larger depression where the lava rock did not accumulate to as great a depth as elsewhere. On this hypothesis it is not very remarkable that in this region, where "sinks" are so abundant even along the major streams, there are few lacustrine deposits. The isolated basins might perhaps be accounted for by downfaulting or by downfolding, but no evidence has been found suggesting that either of these processes has taken place. The valley near Arco heads against a mass of lava rock 800 feet high and 5 miles across, beyond which a similar but smaller reentrant, in perfect alignment with the one from the south, extends from the valley of Little Lost River. It seems quite obvious that Little Lost River once flowed out past Arco and that the waters were diverted to their present channel by the eruption of lavas in the vicinity of Arco Pass. Similarly the other basins are believed to be unfilled segments of much larger depressions whose origin must be studied in the light of preexisting topography.

EARLIER TOPOGRAPHY.

The lava belts in the main occupy valleys of erosion which are parts of an older surface recognized at many places in east-central

Idaho.[1] The lava-flooded valley that crosses the Lost River Range north of Leslie is a narrow gorge where it comes down to the floor of the Big Lost River valley, but it widens northward and finally continues as the open valley of Pahsimeroi River. The contact of the eruptive rocks with the older formations along its course is clearly exposed in many places where canyons cross it. The surface beneath the lavas in many such exposures is covered by rubble, much of which is inclosed in the eruptive rock; elsewhere the lavas abut the eroded edges of the steeply folded sedimentary beds. The depth of this old valley can not be definitely determined, but it certainly attained a much lower level than the present stream channels. From the vicinity of Leslie, where it comes down to the floor of the Big Lost River valley, it presumably increases in depth toward the north, where it widens greatly.

The ancient valley of which Copper Basin is an unfilled segment is less clearly defined than the one that crosses the Lost River Range. The lava that occupies it in large part extends as a belt to the northwest well beyond the limits of the area mapped and on the south joins the Snake River plains in the vicinity of Martin and possibly also east of Muldoon. An extension from this lava belt reaches eastward into the present drainage basin of Alder Creek and thence connects on the south with the Snake River plains east of Timber Mountain. In this part of the area the lavas seem to have accumulated above the level of many of the divides, thus making the delimitation of the old valleys less definite here than elsewhere.

Closely related to these old lava-flooded valleys are others which have remained unfilled throughout their history. The valley occupied by Birch Creek and Lemhi River is fully as wide at the divide, where for a distance of about 8 miles there is no running water, as at any other place. This valley, which is believed to be due principally to erosion, certainly is not the product of the present streams. As was concluded in the study of its northern end [2] it was developed by a stream flowing southeastward from a point north of Salmon City. At a time comparatively late in the history of this valley the stream was tapped by Salmon River and the divide thus formed was driven back by the headward erosion of one of its tributaries, Lemhi River. The north end of the old valley is filled deeply with Miocene lacustrine deposits, which are well exposed in the vicinity of Salmon City.[3] These are believed to extend southward beneath the alluvial mantle that covers the floor of the Birch Creek valley and probably beneath the Snake River lavas.

The Little Lost and Pahsimeroi valleys seem to have been developed by streams that flowed in opposite directions and occupied channels whose upper ends were nearly parallel and only a few miles apart. The many interesting physiographic features about the heads of these two streams were not studied in detail, but it appears that Mill Creek occupies the head of the old Little Lost River valley and that the former Pahsimeroi Valley headed north of Leslie. It is not unlikely that the lower part of the latter valley was the site of a lake during the interval between the outpouring of the lava and the cutting of Salmon Canyon up to the mouth of Pahsimeroi River. Such a lake would have drained out through the valley of Little Lost River, but it is possible that this basin also held a body of water, for there is no evidence of cascades or the work of a rapidly flowing stream on the east side of the divide, and it seems not improbable that the Snake River valley at this time was a lake basin. If, however, there are lacustrine deposits beneath the alluvium that floors these open valleys no exposures of them are known, unless the lake beds north of Pass Creek summit, at an altitude well above that of the valley floors, represent an elevated portion of beds elsewhere concealed by alluvium. These beds crop out over an area of a few square miles as thinly laminated deposits clearly laid down in standing water. (See p. 35.) The beds are interleaved along their west margin with lava sheets and themselves contain large quantities of volcanic ash intermixed with sedimentary débris.

The valley of Big Lost River, more nearly than any of the other large valleys, can be accounted for by the stream that now flows in it, though it was possibly assisted by faulting, as suggested by triangular facets on its eastern

[1] Umpleby, J. B., An old erosion surface in Idaho; its age and value as a datum plane; Jour. Geology, vol. 20, No. 2, pp. 139–147, 1912. Blackwelder, Eliot, The old erosion surface in Idaho; a criticism: Jour. Geology, vol. 20, No. 5, pp. 410–414, 1912. Umpleby, J. B., The old erosion surface in Idaho; a reply: Jour. Geology, vol. 21, No. 3, pp. 224–230, 1913.

[2] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, p. 29, pl. 1, 1913.

[3] Idem, pp. 35–40.

wall. In places it cuts across areas of eruptive rocks, indicating that much of its development was later than the extrusion of the lavas, and possibly these areas mark a second stage of broad valley development. Alluvium covers its floor deeply through its entire extent. At the Mackay dam drill holes 100 feet deep did not reach the base of loose débris. It would not be at all surprising if lake beds several hundred feet thick separate the alluvium from the underlying Paleozoic formations. This is suggested by the relation of the Birch Creek valley, which certainly held a lake, to the Snake River plains, beneath which Russell supposed the Payette formation, a lacustrine deposit, to extend.[1] From what is known of the early Tertiary topography of southern Idaho there is no reason for supposing that the lake at Salmon was separated from the lower end of the Snake River valley in which the Payette lake existed. If there was a continuous body of water between these localities the valleys of Little Lost and Big Lost rivers were very likely arms of the same lake. If lakes existed here, however, direct evidence of them is well concealed beneath the thick sheet of alluvium that is spread over the lowlands.

VALLEY GRAVELS AND ALLUVIUM.

The major valleys of the region are being slowly deepened at present, but in no place do the larger streams occupy inner channels more than a few feet deep. In other words, the principal present-day streams are almost in adjustment, the slight variation from it being on the side of degradation. In comparatively recent geologic time, however, aggradation along the larger valleys was the dominant process, gravels from the adjacent mountains accumulating to depths of more than 100 feet, at least in some places. Prior to this period of aggradation and possibly separated from it by a lacustral stage there was a period of active erosion during which the great valleys were carved out. The cause of the marked change from conditions of active erosion to those of deposition is not altogether clear. The immediate cause was probably the reduction in velocity of tributary streams from the mountains on reaching the valley flats along the trunk channels, but it is not apparent why this reduction in velocity was greater than before the period of aggradation or much greater than immediately after that period. It would seem that the streams must either have been supplied with more material in their upper courses during this period than at other times, or that the annual precipitation was so distributed as to cause many temporary torrents. At about the time the gravel was deposited the mountains above 8,000 feet and the larger canyons down to possibly 7,000 feet were covered with perennial fields of ice. The margins of these fields advanced each winter, carrying forward vast loads of rock débris, and retreated each summer, exposing this loose material to erosion and at the same time supplying water for its transportation. This seems a reasonable explanation for the deposits of this area, but the phenomena in Utah, where similar aggradation has taken place adjacent to low nonglaciated mountains, either during a low stage of Lake Bonneville or before it was formed, are explained by Gilbert[2] as the result of arid conditions. If this interpretation is adopted for the Mackay region it must be concluded that the gravel deposits are pre-Pleistocene, as there is no evidence of arid conditions after that epoch and as the Pleistocene was obviously not lacking in precipitation. It follows that if the age of the gravels were known the uncertainties of their genesis and correlation would be greatly reduced, but there is no known evidence defining their age more closely than post-Miocene (because they cover Miocene beds in Lemhi Valley) and earlier than late Pleistocene.

RELATION TO ADJACENT TYPES.

In preceding sections it has been shown (1) that the mountains of the Mackay region comprise extensions from the great plateau area of central Idaho; (2) that the old lava-flooded valleys of adjacent regions extend into this one; and (3) that lake beds similar to those in Lemhi Valley probably underlie the Birch Creek valley and possibly also the valleys of Big Lost and Little Lost rivers. Clearly, the area has had the same general physiographic history as that to the north and west, with which it agrees in general aspect. An old erosion surface believed to be of Eocene age extends over much of Idaho and is a valuable

[1] Russell, I. C., Geology and water resources of the Snake River plains of Idaho: U. S. Geol. Survey Bull. 199, p. 59, 1902.

[2] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 220-223, 1890.

datum plane in broad areas where the time relations between the Algonkian and the Pleistocene are otherwise obscured. In this region the dissection of the upland is so far advanced that the former existence of a high-level surface of even contour would scarcely be suspected, except for the proximity of areas in which it is clearly defined and the similarity in the relations and distribution of the lava-flooded valleys here and there.

PHYSIOGRAPHIC HISTORY.

The record of the physiographic history of the Mackay region, as interpreted largely in the light of what is known of adjacent areas to the west and north, is legible for only that comparatively small portion of geologic time since the late Mesozoic. Near the end of the Cretaceous period great crustal movements raised the surface to an altitude of several thousand feet, rejuvenating the streams and initiating a period of rapid erosion, which by the end of Eocene time had reduced the surface nearly to the base level for the area, possibly 1,000 feet above sea level. At this time an even surface of degradation extended across the intricately folded strata of the area, the resistant and nonresistant rocks alike having about the same relief.

Late in the Eocene or early in the Oligocene this lowland was raised to a height near the present summit level, a total uplift, possibly as a continuous movement but more likely as a succession of movements, of about 10,000 feet. The streams once more became active agents in reducing the surface, the larger ones developing broad, deep valleys, many of which received lava flows and lacustrine deposits in Miocene and possibly also in part of Pliocene time.

Then followed another period of dominant erosion during at least the early part of the Pliocene. Valleys as much as 4,000 feet deep were carved in the Miocene rocks and later shaped by ice. During the later part of this epoch the lowlands may have been aggraded, because of special climatic conditions, although the thick alluvial deposits along the larger valleys may have been formed in late Pleistocene time, when glacial ice was retreating to higher levels and delivering vast quantities of loose débris to the mountain torrents.

Ice fields covered the uplands during the Pleistocene epoch and extended down the larger valleys to altitudes of about 7,000 feet. Many of the scenic features of the region—the great cirques at the heads of the canyons, the beautiful mountain lakes, the grassy valleys near the divides, and the general conspicuous contrast between rounded contours where glaciers worked and ragged surfaces where they were absent—date from this epoch.

GENERAL GEOLOGY.

LEADING FEATURES.

The rock formations of the Mackay region include several thousand feet of widely distributed Paleozoic beds comprising Cambrian (?) quartzite, Ordovician quartzite, and dolomite, Devonian dolomite, limestone, and calcareous shale, Mississippian limestone, and Pennsylvanian limestone, calcareous sandstone, and shale. (See Pl. I, in pocket.) In the northern part of the area these formations rest upon a series of intensely metamorphosed schists, slates, and quartzites, but in the southern part their base is not exposed. The Mesozoic era is not represented in the area by stratified rocks, but intrusive granite and related rocks that are probably of late Cretaceous age occur in the central and southwestern parts.

An Eocene erosion surface is believed to have extended across this region before the formation of the great lava-flooded valleys that traverse the region. Fields of glacial ice occupied the highlands in Pleistocene time and extended down the larger valleys to altitudes of about 7,000 feet. Gravels, at least in part deposited during the retreat of this ice, mantle the floors of the larger valleys and possibly conceal lacustrine deposits of Miocene age.

The structural relations in the region are so complex that it was not possible to work out a complete section in the time available for the stratigraphic part of the reconnaissance. In a great many places 2,000 to 3,000 feet of beds occur in normal sequence, but as these are only small segments of a section monotonous in the similarity of its formations, it is believed to be impossible to correlate them satisfactorily except by detailed observations and careful study of the many fossil horizons. In the following pages many partial sections and lists of fossils are presented, more for the purpose of making the material available for future investigators in the region than as a basis for present interpretation and correlation. Indeed, most of the attempts at correlation in this paper are made only for their suggestive value.

PROTEROZOIC ROCKS.

ALGONKIAN SYSTEM.

Rocks believed to be of Algonkian age crop out in the vicinity of Bell Mountain, on the west flank of the Lemhi Range. They are well exposed in the lower mile of Basinger Canyon, where they comprise fine-grained sericitic schists and micaceous quartzites of dark-gray color. They are uniformly though not intensely metamorphosed. Crumpling is not common, and in most of the quartzitic members the original bedding planes may be clearly traced almost at right angles to the planes of schistosity. On the east the Algonkian rocks are separated from fine-grained white quartzite, tentatively referred to the Ordovician, by a normal fault which crosses the canyon about a mile from its mouth.

Similar rocks were observed in the first canyon south of Basinger Canyon. Here, however, there is some suggestion of a depositional contact between the Algonkian and the overlying white quartzite, although the exposure is poor.

To the north the Algonkian beds are widely exposed in the Lemhi Range, the contact with the Paleozoic beds gradually mounting the range and finally descending to Lemhi Valley in the vicinity of Stroud station.[1] The beds are believed, from their advanced metamorphism and their lithologic similarity, to be part of the Belt series, which is widely exposed in Idaho and western Montana.[2]

PALEOZOIC ROCKS.

CAMBRIAN (?) SYSTEM.

DISTRIBUTION AND LITHOLOGY.

Rocks believed to be of Cambrian age are exposed in many parts of the Mackay region, but only in the vicinity of Wilbert were they carefully examined, and here neither the top nor the bottom is exposed. Their upper members are faulted against massive-bedded blue dolomite and their basal members disappear beneath Tertiary (?) alluvium. The fine-grained white quartzite that occurs in the Gilmore section and was assigned to the Cambrian in the report on Lemhi County[3] crops out at several places in the Mackay region, but is here tentatively assigned to the Ordovician.

The supposed Cambrian quartzites in the vicinity of Wilbert, in the Lemhi Range, include four fairly distinct formations that are designated lower quartzite, shale, middle quartzite, and upper quartzite. (See Pl. III, *B*.) The lower quartzite is a massively to semimassively bedded white rock that has a wide range in texture but is in most places pebbly, containing subangular pebbles of quartz as much as a quarter of an inch across, firmly cemented by finer siliceous material. The base is not exposed, but 200 feet of beds appear in the canyon side below the Wilbert mill.

A shale formation, intricately folded in the vicinity of the mill but apparently about 150 feet thick, overlies the lower quartzite. The rock is greenish gray and has been so greatly compressed that it breaks readily into irregular plates with curved faces. Its metamorphism was accompanied by the development of considerable chlorite and sericite.

Above the shale formation is the middle quartzite, which, as exposed in nearly vertical beds along the canyon above the Wilbert mill, is 475 feet thick. The rock has a maroon color that contrasts sharply with the prevalent light grays of the other quartzite formations. The lower part of it is made up of thick beds, some of which are intricately cross-bedded, but the upper layers are thin and regularly stratified.

Overlying this formation is an assemblage of quartzite beds that were grouped and mapped as the upper quartzite. They are at least 800 feet thick, although, as there is a strong fault on the east, their full thickness was probably not observed. The lowest beds consist of 25 feet of milky-white fine-grained quartzite, overlain by 6 feet of dark-gray medium-grained quartzite, then 10 feet more

[1] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, pl. 1, pp. 30-32, 1913.

[2] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, p. 35, 1913.

[3] Umpleby, J. B., op. cit., pp. 32-33.

of the milky-white variety, which grades into a brownish facies containing numerous annelid borings, the total to this horizon representing a thickness of about 170 feet. Above this lower group of beds is 80 feet of thin-bedded clear-white fine-grained quartzite, which from local evidence might be considered a distinct unit. This is overlain by 550 feet of massive quartzite beds of light-gray color and fine-grained texture.

AGE AND CORRELATION.

These rocks are clearly ancient sediments, and, as there appears to be no place for them higher in the section, they are believed to be most likely of Cambrian age. If they are Cambrian, however, the section is very different from that in northern Utah described by Richardson.[1] The lower quartzite here corresponds fairly well in lithology with the Brigham quartzite of the Utah section, but if the shale corresponds to the Hodges shale member of the Bloomington formation, then the Blacksmith, Ute, and Langston limestones are absent. Also if the middle and upper quartzites correspond to the Worm Creek quartzite member of the St. Charles limestone of that section, then the Nounan limestone and upper part of the Bloomington formation are absent. The correspondence of the Mackay section with the Cambrian section of western Montana is even less close, for if the lower quartzite is considered the equivalent of the Flathead quartzite, and the shale equal to the Silver Hill formation, the magnesian limestones and shale of the Hasmark formation and the limestone and shale of the Red Lion formation have their equivalent in the middle and upper quartzites of the Wilbert section.[2]

ORDOVICIAN SYSTEM.

Three Ordovician formations, the lowest of which is, however, only tentatively assigned to that system, are recognized in the Mackay region. The upper two are fossiliferous dolomites; the lower is a fine-grained white quartzite not known to contain fossils. The base of the system is not exposed, but in Elbow Canyon there are 1,600 feet of quartzite beds overlain apparently conformably by 420 feet of dark-blue dolomite, above which is 530 feet of white dolomite, and the two dolomites yield a Richmond fauna.

QUARTZITE FORMATION.

The quartzite formation is exposed in Elbow Canyon on the east limb of an anticline into which the stream has not cut sufficiently to reveal the base. The rock throughout is uniformly so fine grained that with the unaided eye individual grains can not be distinguished. As measured in thin section with a microscope they are seen to average about 0.4 millimeter in diameter, the largest one measured being only 0.7 millimeter. They are rounded to subangular in outline and interlock closely.

Similar rock occurs in the second ridge east of Arco, but here it has been minutely fractured and the openings sealed by cryptocrystalline quartz. About 800 feet of beds are exposed at the head of a small canyon on the west slope of the ridge. Upon them rest thick-bedded dark-blue dolomite that continues to the summit, 200 feet above. Similar quartzite is abundant in the alluvial gravels near Dickey—a fact which, with the occurrences at the other localities mentioned, suggests that the formation is widely distributed in the Lost River Range.

In the Lemhi Range what seems to be the same formation crops out in Basinger Canyon about a mile from its mouth. Above it are massive beds of blue dolomite lithologically similar to those yielding the Richmond fauna in Elbow Canyon; below it, separated by a normal fault, are schists and quartzites, probably of Algonkian age. Farther north along the Lemhi Range a similar quartzite formation occurs at the head of Meadow Lake, near Gilmore. This rock was assigned to the Cambrian in the report on that area,[3] but for reasons presented on page 25 it is now believed to be Ordovician. Its stratigraphic relation to thick-bedded dolomite yielding Richmond fossils is exactly the same as that of the similar quartzite in Elbow Canyon.

DOLOMITE FORMATION.

The upper Ordovician comprises two distinct lithographic units, both thick bedded—an upper white dolomite and a lower dark-blue dolo-

[1] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 33, pp. 406–407, 1913.

[2] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, pp. 51–60, 1913.

[3] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, pp. 32–33, 1913.

mite. The rocks were seen at several places in the Lemhi and Lost River ranges, but were examined in detail only in the Elbow Canyon section east of Mackay. The lower dolomite rests, with apparent conformity, upon the fine-grained white quartzite above described. It forms cliffs many feet high, in which the more resistant beds are separated by thin, platy layers that contain abundant poorly preserved fossils. Near the base of the blue dolomite fossils collected by the writer and G. H. Girty were identified by Edwin Kirk as a cephalopod siphuncle, genus undetermined, *Halysites gracilis*, and *Streptelasma* sp. About 400 feet higher in the section, but still in the blue dolomite, the beds contain abundant fossil fragments, none of which were determinable, although Mr. Kirk ventures the opinion that the material is "probably some sort of stromatoporoid." The blue dolomite, as measured in this section, is 420 feet thick. Above the blue dolomite is massive white dolomite 530 feet thick. Its surface is spotted with clear marble-like patches and is horny and nodular where weathered. The characteristics and composition of the different beds are very similar. They seem to be conformable with the blue dolomite below and the lower Devonian beds above. Fossils were found sparingly at several horizons, and among the material collected Mr. Kirk identified *Dinorthis subquadrata* (Hall) var., *Hormotoma* sp., *Maclurina* sp., and *Streptelasma* sp.

Mr. Kirk concludes from his examination of the fossils that the material from the base of the blue dolomite and that from the white dolomite "are certainly Richmond in age." He found nothing of diagnostic value in the material from the top of the blue dolomite, but as this is definitely between the other two, the entire section must be considered as representing the Richmond epoch of the Ordovician.

CORRELATION.

The dolomite portion of the Ordovician of this region, Mr. Kirk states, "should be correlated with the Fish Haven dolomite of Richardson." The Fish Haven consists of 500 feet of medium-bedded bluish dolomite and is overlain by 1,000 feet of light-gray to white dolomite (the Laketown dolomite) that contains a meager Silurian fauna.[1] In the Gilmore section, to the north, the beds of Richmond age are also about 500 feet thick and similar lithologically. Above them is a light-gray dolomitic limestone 200 feet thick. On lithologic and stratigraphic evidence, therefore, it would seem that the light-gray to white beds overlying the dark-blue formation yielding Richmond fossils in the three areas should be considered of contemporaneous origin. In one of the areas (Utah) fossil evidence points to the Silurian; in another (Gilmore) doubtfully to the Silurian; and in the third (Mackay) definitely to the Ordovician. It is to be hoped that other localities in the general region will afford more extensive fossil collections.

The fine-grained quartzite beneath the dark-blue dolomite should possibly be correlated with the Swan Peak quartzite of Richardson,[2] which is similar in lithology and stratigraphic position, although only 500 feet thick. It is quite certainly the same quartzite formation that is exposed at the head of Meadow Lake, near Gilmore. This was considered to be Cambrian, at the time the Lemhi County report was written, because of "the general presence of quartzite at the base of the Cambrian in many localities to the south and east and its absence in the Ordovician." The recent change in the assignment of the formation is based purely on the following stratigraphic relations and must be considered tentative, as no fossils have been collected from it in the Mackay region: (1) Quartzite of the same uniform texture has recently yielded Ordovician (Chazy?) fossils in the Bear River Range of northern Utah. (2) If the quartzite is Cambrian it is most reasonably assigned to the basal Cambrian, which in other areas is lithologically similar. It is, however, immediately beneath the dark-blue dolomite in each of the four sections where the contact has been studied, but this leaves no room above it for the 1,600 feet of Cambrian (?) beds near Wilbert, and to put those beds below it means that it is either near the base of the Ordovician or near the top of the Cambrian. To give it the latter position makes it contemporaneous with limestone of regions to the south and east, whereas its lithology agrees closely with that of the Ordovician Swan Peak quartzite. This correlation therefore seems more probable.

[1] Richardson, G. B., op. cit., p. 410.

[2] Idem, p. 409.

DEVONIAN SYSTEM.

DISTRIBUTION AND CHARACTERISTICS.

The Devonian system is represented in the Mackay region by about 3,950 feet of beds comprising three distinct formations and so far as observed is conformable with the Ordovician below and the Mississippian above. The upper 500 feet, yielding fossils of Threeforks age, rests upon 1,500 feet of beds from which fossils were not collected, and the basal 1,950 feet yields a fauna with Jefferson affinities. The Devonian rocks were studied in detail only in Elbow Canyon, east of Mackay, but are believed to crop out widely in the Lost River Range, where the middle formation feeds the long talus slopes of fine material that extend as a girdle along the west side of the range near the summit. In the Lemhi Range also rocks that resemble the Devonian in lithology were seen at several places.

The basal formation of the Devonian, as exposed in Elbow Canyon, where the beds stand almost vertical, comprises massive dark-blue and gray dolomite separated by thinner beds of similar but less resistant material. Throughout 300 feet of beds, beginning about 250 feet above the base, there are vast quantities of *Stromatopora?* sp., this fossil making up most of the mass of some of the beds. Near the top of this lower Devonian formation, through 100 feet or more of beds a fossil sponge is fairly abundant. Mr. Kirk, in referring to these collections, says:

> Although the fossils in these two lots are indeterminable generically, they point conclusively to the Devonian (Jefferson) age of the containing beds. These fossils are characteristic throughout the extent of the Jefferson. So far no material sufficiently well preserved for microscopic examination has been obtained, and in consequence it has not been possible to identify the fossils accurately.

Above the dolomite containing the Jefferson fossils are about 1,500 feet of beds which make grassy slopes. Fragments in the soil and piled about gopher holes are rather uniformly of brown calcareous slaty material. These beds did not yield fossils.

The uppermost Devonian formation consists of massively bedded blue and dark-gray limestone and dolomite, of which a few beds stand in much stronger relief than the others, though all are strongly resistant to erosion. At several horizons there are layers of reddish-brown shaly limestone that contain abundant fossils. These were examined by E. M. Kindle, whose report follows:

> I have been able to recognize the following species in the collection of Devonian fossils from Elbow Canyon, Mackay, Idaho, which you [G. H. Girty] recently sent me for study:
>
> Productella sp.
> Camarotoechia sp.
> Schizophoria striatula var. australis.
> Athyris parvula.
> Reticularia sp.
> Spirifer utahensis.
> Spirifer whitneyi.
> Meristella cf. M. barrisi.
> Euomphalus eurekensis.
>
> The fauna represents an Upper Devonian horizon. This assemblage of species shows resemblances both to the Jefferson limestone and the Threeforks shale fauna. The presence in it, however, of a large species of *Productella* appears to indicate that it represents a horizon later than that of the Jefferson fauna. I am inclined to regard it as a calcareous facies of the Threeforks shale fauna, although it is not a typical fauna of this horizon.

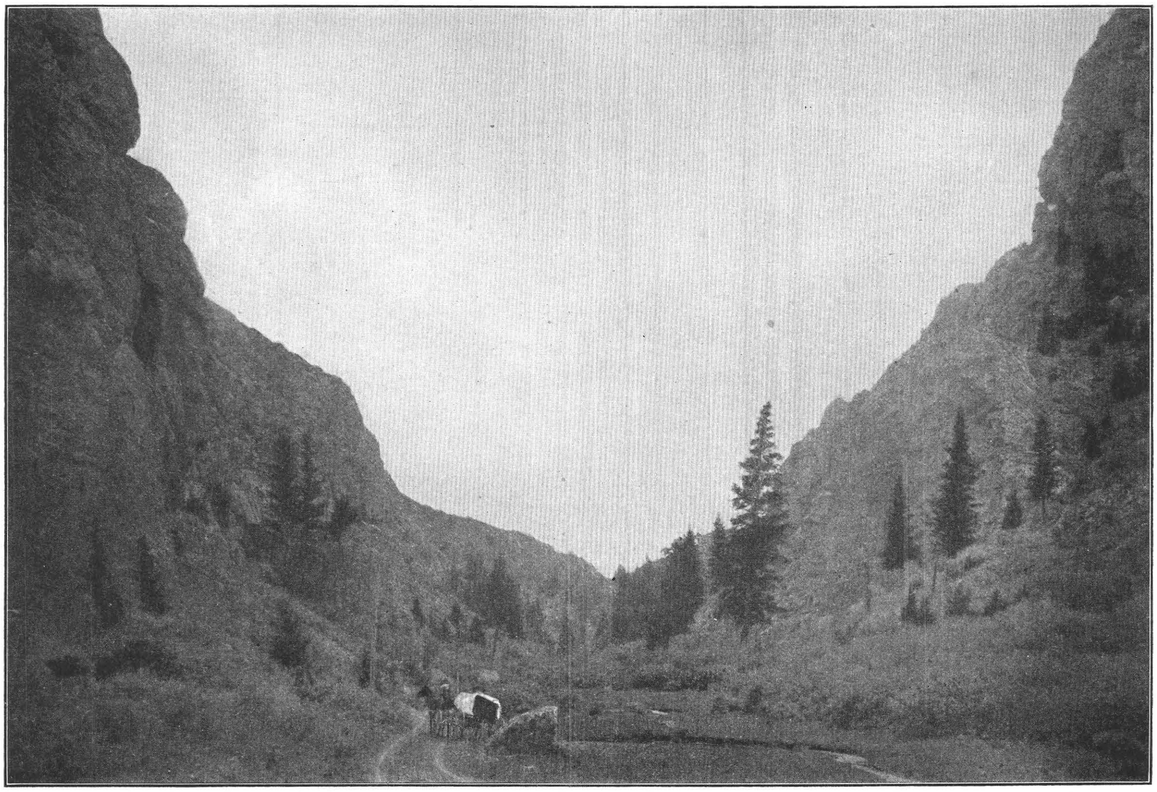
CORRELATION.

Devonian rocks are well known in areas to the north, east, and southeast of the Mackay region, and with them the Devonian beds of this region are correlated on fossil evidence. In the Randolph quadrangle, in northern Utah, the system is represented by the Jefferson dolomite, 1,200 feet thick, and by 200 feet of Threeforks limestone.[1] To the northeast, near Three Forks, Mont., the Devonian comprises a very dark dolomite formation 840 feet thick, known as the Jefferson limestone, and a shale formation, the Threeforks shale, 135 feet thick.[2] In the Philipsburg quadrangle, to the north, the Threeforks is absent, but the Jefferson is about 1,000 feet thick and consists predominantly of rather thick bedded, somewhat magnesian limestone.[3]

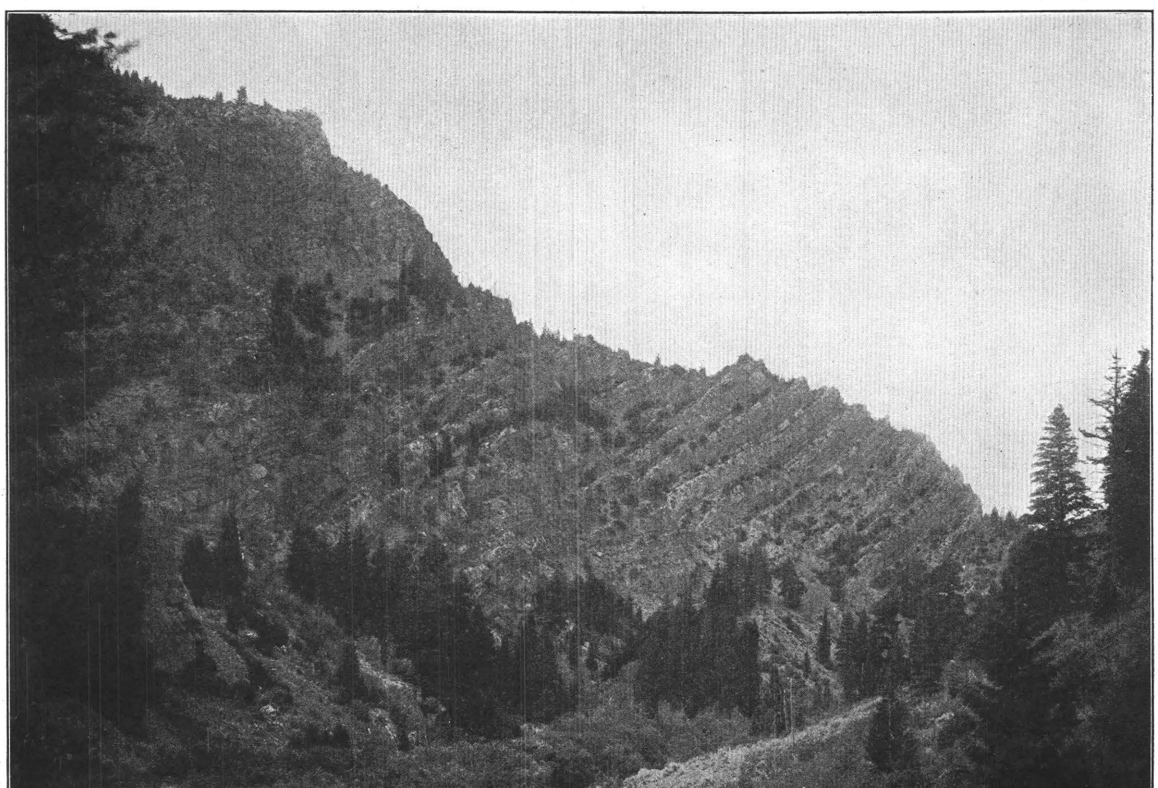
In the southeastern part of Lemhi County, Idaho, the Devonian is at least 2,000 feet thick up to a stratigraphic horizon that "contains corals hitherto referred by Kindle to the Jefferson limestone." Above this horizon the section was not measured, because of structural complications,[4] and fossils were not found.

From the above citations of areas near by it appears that the most noteworthy feature

[1] Richardson, G. B., op. cit., pp. 411–412.
[2] Peale, A. C., The Paleozoic section in the vicinity of Three Forks, Mont.: U. S. Geol. Survey Bull. 110, pp. 27–32, 1893.
[3] Emmons, W. H., and Calkins, F. C., op. cit., p. 65.
[4] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, p. 34, 1913.



A. PASS CREEK CANYON, LOST RIVER RANGE, IDAHO.



B. UPPER MISSISSIPPIAN BEDS EXPOSED IN PASS CREEK CANYON.

of the Mackay Devonian section is its great thickness. It is not possible to know from data now available whether the thickening toward the west is due to an increase principally in the Threeforks or in the Jefferson, because the middle part of the Devonian section in the Mackay region, comprising 1,500 feet of beds, did not yield fossils. Lithologically this part of the section seems to fall with the Jefferson rather than with the Threeforks, which would make the Jefferson about 3,450 feet thick—more than twice its thickness in any of the other localities. It is also worthy of note that in its type locality in Montana the Threeforks is a shale formation lying between resistant limestone beds, and that in northern Utah it is a soft limestone between harder ones, but that near Mackay it appears to be represented by predominantly resistant beds with a soft formation below and presumably with thick-bedded Mississippian limestone above. This difference affords some suggestion that the middle shale member of the Elbow Canyon section should be considered a part of the Threeforks, but that would make the Threeforks ten times as thick in the Mackay region as in either of the other localities.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

DISTRIBUTION AND LITHOLOGY.

Mississippian beds that have yielded extensive fossil collections at many places are widely distributed and of great thickness in the Mackay region. A complete section has not been found, and the fragmentary information collected during the reconnaissance does not warrant the piecing together of even a tentative section. In general the series consists of a monotonous succession of thick-bedded and thin-bedded limestones, with variations in the color of widely separated beds as the principal present basis of correlation. In several localities partial sections including from 1,000 to 4,000 feet of beds are exposed, and some of them quite certainly comprise beds at horizons not represented in others; but all that can be said now is that the series is very thick, probably much more than 6,000 feet.

The beds from which fossils were collected are all of upper Mississippian age, the lower Mississippian or Madison limestone, which is so widely distributed in the Rocky Mountain region, apparently being absent.

The most detailed section was measured in Joggle Canyon, east of Mackay, where east of a disturbed zone about 4,300 feet of beds are exposed in the upper third of the canyon. The beds dip about 80° E. in the lower part of the exposure, but flatten to 25° toward the head of the canyon. The lower beds exposed are 1,500 feet of thin-bedded fine-grained calcareous slate, which becomes somewhat thicker bedded near the top. Conformably above these beds is 400 feet of buff and pale-maroon shale with a few thick beds of fossiliferous limestone (1140, 541 [1]) near the base. Above the shale beds is 200 feet of dark limestone in thin beds, which become thicker upward and lie beneath a medium-bedded limestone (536) of distinctive reddish-buff and blue color. Above this limestone is 300 feet of massively bedded dark-blue limestone (1136, 540), which grades upward into 100 feet of buff sandstone. Then follows 100 feet of clayey limestone (1137), which weathers a bright red. Above this 1,050 feet of thick-bedded blue limestone remarkably free from partings along the bedding continues to the summit; fossils were found only in the lower 200 feet (1138).

The section east of the Empire mine, representing, perhaps, 4,000 feet of beds, is very different from the one just described, comprising a monotonous succession of limestone beds of almost uniform dark-blue color, rather pure in the upper part, but with notable amounts of chert in the lower members. The chert occurs as nodules, lenses, and apparently also as thin beds, locally making up 25 per cent of the mass. Fossils were collected from beds about halfway up in the section (79) and near the top (542).

A section about a mile above the lower entrance to Pass Creek canyon (see Pl. IV) presents about 2,000 feet of strata. The lower part consists of beds of dark-blue limestone as much as 20 feet thick, through which are sparsely scattered lenses and nodules of chert. This series grades upward into a shaly limestone in beds 1 to 2 feet thick, in the upper third of the section. Abundant fossils occur in the lower beds (1141, 1141a, 1141b, 1141c) and a few were found in the upper beds (1142, 1143).

[1] The numbers in these descriptions refer to the lots of fossils collected from the particular strata described and correspond to the permanent numbers of the lots in the Survey record of Carboniferous invertebrate collections. The fossils are listed on pages 29-30.

Neither the top nor the base of the Mississippian is known to be exposed in any of the above-described sections. In Elbow Canyon, the only place where Devonian fossils were collected, a fault probably separates beds yielding an upper Mississippian fauna from those of Devonian age. The top of the Mississippian, however, may be exposed near the summit of the range east of Moore, where above a fairly distinct lithologic break were collected fossils (539) which G. H. Girty refers tentatively to the lower Pennsylvanian. This section comprises about 2,000 feet of dark-blue Mississippian limestone (534), inclosing some thin beds of gray color. It forms cliffs 5 to 30 feet high, separated by terrace-like benches, except in the middle 500 feet or so, where the slopes are smooth. The overlying Pennsylvanian affords smooth slopes broken by one cliff 30 feet high, made up of alternating layers of cherty limestone and nodular sandstone, and another 15 feet high, made up of thin-bedded sandy and cherty limestone. These cliffs, which are separated by about 200 feet of concealed beds, both yield the fauna tentatively assigned to the lower Pennsylvanian.

AGE AND CORRELATION.

The Mississippian beds of the Mackay region are highly fossiliferous. Many collections were made from that part of the Lost River Range east and south of Mackay, where alone time was given to a search for them. The collections have proved to be of unusual interest, and as the correlation of Carboniferous formations in the Rocky Mountain region are in process of gradual revision, G. H. Girty, who identified and helped to collect the fossils, has kindly supplied the subjoined brief statement concerning the special features of the Mississippian of the Mackay region with respect to some of the general problems he has been investigating for a number of years:

With but few exceptions, all the Carboniferous collections made in the Mackay region can be assigned to the upper Mississippian. None of them possesses the characteristic Madison (lower Mississippian) facies, and as the Madison limestone is usually recognizable with ease, both faunally and lithologically, that horizon may with reasonable safety be regarded as unrepresented among the fossil collections. There are, however, a few lots containing faunas so small and poorly characterized that their evidence is as inconclusive negatively as it is positively. The Pennsylvanian series, on the other hand, is represented by a few characteristic faunas. These are lots 538, 539, and 544, all the rest being assigned to the upper Mississippian.

Faunally these collections are of unusual interest. Some of them show a distinct alliance with the faunas of the Mississippi Valley (for example, lots 1140 and 1141 especially recall the fauna of the Moorefield shale of Arkansas), while others are more nearly allied to the Mountain limestone or *Productus giganteus* zone of Europe and Asia (lots 1141a and 1145), an alliance shown in the large *Productus* identified as *P. latissimus*, in the abundance of corals of the genus *Lithostrotion*, and in other species. There is no apparent reason why these two facies should not be considered to belong to essentially the same geologic period.

Over extensive areas in the West rocks of upper Mississippian age appear to be lacking, so that the Pennsylvanian rests directly upon the Madison limestone or upon older strata. Upper Mississippian rocks are, however, known in Montana, Utah, Idaho, California (Baird shale), and Alaska (Lisburne limestone). It is probable that the typical Quadrant formation is of that age, though this is not certain. Evidence also exists for believing that the Madisone limestone itself is in part upper Mississippian, or at least that upper Mississippian rocks have been included in mapping with the abundantly and characteristically fossiliferous Madison strata. The Brazer limestone of northern Utah is also regarded as of upper Mississippian age, and to the same formation has been assigned a much thicker and more richly fossiliferous series of rocks in the Montpelier region, in southeastern Idaho. In the Eureka district of Nevada the White Pine shale, the Diamond Peak quartzite, and the "lower Carboniferous" limestone are all tentatively assigned to the upper Mississippian, and if so they constitute one of the thickest sections known, comprising nearly 9,000 feet of strata. In point of thickness at least the Mackay section is more comparable to that of the Eureka district than to any of the others mentioned.

The great thickness of the upper Mississippian of the Mackay region is its most striking feature as compared with sections in near-by areas. In northern Utah the upper Mississippian is represented by the Brazer limestone, which consists of 800 to 1,400 feet of massive to thin-bedded light-gray siliceous limestone, including some sandstone beds, and rests on highly fossiliferous Madison limestone of about equal thickness.[1] The overlying Pennsylvanian beds consist of 300 to 600 feet of thin-bedded quartzite and limestone, grading upward into massive quartzite. In the Philipsburg area the upper Mississippian is absent, an unconformity (?) separating the Madison limestone from the Pennsylvanian rocks.

The fossils collected from the Mississippian of the Mackay region by the writer in 1912 and by the writer and Mr. Girty in 1913 are listed below with approximate localities. The num-

[1] Richardson, G. B., op. cit., pp. 412-413.

bers at the head of the lists, with the exceptions of Nos. 1, 2, 5, 8, 55, and 79, which were given in the field, correspond to the permanent numbers in the Survey record of Carboniferous collections.

533. From semimassive limestone near head of Ramshorn Canyon:

Derbya kaskaskiensis (?).
Chonetes aff. C. burlingtonensis.
Spirifer aff. S. peculiaris.
Spiriferina sp.

534. From massive blue limestone forming lower part of range east from Moore, near top of lower 1,200 feet of exposed beds:

Rhombopora sp.
Streblotrypa sp.
Cystodictya sp.
Batostomella sp.
Stenopora sp.
Derbya kaskaskiensis?
Productus pileiformis.
Productus inflatus?
Girtyella turgida var. elongata.
Spirifer keokuk var.
Spiriferina sp.
Martinia sp.
Composita subquadrata.
Cliothyridina hirsuta.
Nucula levatiformis?
Nucula rectangula?
Cypricardella oblonga.
Sphenotus sp.
Euomphalus similis var. planus.
Platyceras sp.
Holopea proutana?
Holopea n. sp.
Loxonema yandellanum var.
Aclisina turritella?
Pleurotomaria, 3 n. sp.
Kirkbya sp.

535. From massive blue limestone about halfway up Elkhorn Canyon:

Campophyllum? sp.
Anisotrypa sp.
Batostomella? sp.
Fenestella sp.
Lingulidiscina? sp.
Crania? sp.
Derbya kaskaskiensis?
Chonetes sp.
Productus punctatus.
Productus pileiformis.
Diaphragmus elegans.
Girtyella turgida?
Spirifer keokuk var.
Composita trinuclea.
Cliothyridina hirsuta.
Conocardium sp.
Aviculipecten, 2 sp.
Paraparchites sp.
Bairdia sp.
Griffithides sp.

536. From buff and blue limestone 350 feet thick near head of Joggle Canyon:

Lithostrotion, 3 sp.
Syringopora sp.

537. From slide rock, 8,300 feet elevation, on slope 3 miles northeast of Mackay:

Zaphrentis multilamella?
Batostomella sp.
Fenestella sp.
Cystodictya? sp.
Rhombopora sp.
Chonetes sp.
Productus sp.

540. From massive blue limestone, 400 feet exposed at head of Joggle Canyon:

Zaphrentis sp.
Syringopora sp.

541. From arenaceous shale and blue limestone, 400 feet thick, which lies next below buff and blue limestone near head of Joggle Canyon:

Batostomella sp.
Productus pileiformis.
Productus arkansanus.
Productus n. sp.
Productus inflatus?
Pustula aff. P. moorefieldana.
Productella hirsutiformis?
Spirifer arkansanus?
Paraparchites nicklesi?

542. From massive blue limestone near Empire mine, Alberta portal:

Campophyllum? sp.
Zaphrentis sp.

543. From limestone at quarry near Arco:

Crinoidal fragments.
Stenopora? sp.
Productus inflatus.
Spirifer keokuk var.
Composita? sp.

545. From limestone beds about 4 miles east of Arco:

Zaphrentis multilamella?

546. From massive limestone exposed in 1,000-foot section, 6 miles north-northeast of Arco:

Zaphrentis multilamella?
Syringopora sp.

1. From limestone bed, 100 feet thick, 5 miles east of Mackay:

Fenestella sp.
Polypora sp.
Rhombopora sp.
Cystodictya? sp.
Productus cora.

2. From limestone $5\frac{1}{2}$ miles east of Mackay:

Syringopora aff. S. surcularia.
Crinoid stems.

5. From massive limestone $1\frac{1}{2}$ miles west of Pass Creek summit:

Syringopora aff. S. surcularia.
Campophyllum? sp.
Productus aff. P. inflatus.
Spirifer keokuk var.

8. From medium-bedded limestone, about 1,000 feet thick, $1\frac{1}{2}$ miles west of Pass Creek summit; stratigraphically above 5:

Syringopora sp.
Campophyllum? sp.
Derbya kaskaskiensis.
Composita subquadrata.

55. From massive limestone 35 miles northeast of Arco (in central part of T. 9 N., R. 31 E.):

Zaphrentis sp.
Productus aff. inflatus.
Productus aff. P. arkansanus?

79. From limestone exposure 1,000 feet east of Alberta portal, Empire mine:

Syringopora sp. (like that in lot 8).
Fistulipora sp.
Fenestella sp.

1136. From massive siliceous limestone near head of Joggle Canyon:[1]

Syringopora sp.
Lithostrotion whitneyi.
Melonites? sp.
Crinoid.
Rhipidomella nevadensis.
Productus aff. P. parvus.
Productus aff. P. setiger.
Productus sp.
Camarophoria explanata?
Spirifer keokuk var.
Cliothyridina aff. C. sublamellosa.
Paraparchites sp.

1137. From about the same horizon as 1136 but 1,000 feet away along the outcrop:

Lithostrotion whitneyi.
Lithostrotion sp. a.

1138. From massive limestone above 1136:

Zaphrentis stansburyi?

1139. From limestone forming summit at head of Joggle Canyon:

Zaphrentis sp.
Batostomella sp.
Spirifer keokuk var.?

[1] Lots 1136–1140 were collected in 1913 from the same section which in 1912 yielded lots 536, 540, and 541.

1140. From limestone about 200 feet below 1136:

Batostomella sp.	Productus ovatus?
Cystodictya sp.	Productus tenuicostus.
Bactropora sp.	Productus sp.
Chonetes aff. C. illinoisensis.	Girtyella? sp.
Productella hirsutiformis var. batesvillensis?	Camarotoechia? sp.
Productella hirsutiformis?	Spirifer keokuk var.?
Productus subsulcatus?	Reticularia setigera?
Productus moorefieldanus?	Aviculipecten 2 n. sp.
Productus biseriatus?	Platyceras sp.
Productus aff. P. longispinus.	Paraparchites nicklesi.

1141. From talus in lower 500 feet of 2,000-foot section exposed in Pass Creek Canyon. The collection was separated into four lots according to probable stratigraphic horizons:

Zaphrentis? sp.	Camarophoria thera?
Lithostrotion whitneyi?	Girtyina brevilobata.
Ptilpora sp.	Dielasma aff. D. formosum.
Fenestella several sp.	Spirifer arkansana?
Cystodictya lineata?	Spirifer keokuk var.
Rhombopora? sp.	Spirifer sp.
Bactropora sp.	Spiriferina sp.
Batostomella sp.	Martinia sp.
Stenopora sp.	Composita trinuclea?
Crania sp.	Cliothyridina sublamellosa?
Chonetes aff. C. illinoisensis.	Hustedia sp.
Productus punctatus.	Myalina aff. M. sanctiludovici.
Productus inflatus?	Aviculipecten morrowensis?
Productus arkansanus?	Schizodus? sp.
Productus parvus?	Solenospira aff. S. attenuata.
Productus sp.	Griffithides sp.
Productus aff. P. indianensis.	Bairdia sp.

1141a. In same section principally above 1141:

Zaphrentis stansburyi?	Batostomella sp.
Lithostrotion? sp. b.	Schizophoria aff. S. resupinata.
Amplexus sp.	Productus latissimus.
Cyathophyllum subcaespitosum?	Cliothyridina sublamellosa?
Cystodictya lineata?	

1141b. Principally higher in the section than 1141a:

Fenestella sp.	Dielasma sp.
Batostomella sp.	Spiriferina sp.
Productus aff. P. parvus.	Cliothyridina sublamellosa?
Productus aff. P. inflatus.	

1141c. Principally higher in the section than 1141b:

Zaphrentis sp.	Productus sp.
Stenopora sp.	Dielasma sp.
Schuchertella? sp.	Spirifer keokuk var.?
Diaphragmus elegans?	Cliothyridina sublamellosa?

1142. From about two-thirds of the way up in the Pass Creek section:

Batostomella sp.	Productus latissimus?
Dielasma sp.	

1143. From near the top of the Pass Creek section:

Zaphrentis sp.	Cliothyridina? sp.
Dielasma sp.	

1145. From limestone talus about 3 miles above the mouth of Elbow Canyon; occurs adjacent to the Devonian but probably the two are separated by a fault:

Zaphrentis excentrica?	Productus latissimus.

PENNSYLVANIAN SERIES.

DISTRIBUTION AND LITHOLOGY.

The Pennsylvanian series attains its maximum development in the Mackay region in the vicinity of Muldoon, although small areas of Pennsylvanian rocks occur in the east end of the Lost River Range and rocks of the same age probably crop out in the Lemhi Range and east of Birch Creek. The only considerable section measured is well exposed a few miles west of the area mapped, on the north rim of Muldoon Canyon about 2 miles east of Bellvue. Here the rock exposures are good and the structure involves only regular easterly dips. The section was measured in 1913 by the writer in company with G. H. Girty and E. H. Finch. Measurements were made by pace traverse, lock level, and aneroid, and record was kept of the surface slope, the course of the traverse, and the dips of the beds. The section is not complete, as erosion has removed the top of the series in this locality, but it is believed to contain the base of the Pennsylvanian, although its exact stratigraphic position has not been determined.

Section of Pennsylvanian series east of Bellvue, Idaho.

	Feet.
Sandstone, brown and fine grained, in beds from 1 foot to 6 feet thick; top not exposed	240
Limestone, siliceous, coarse textured, of blue color, weathering dull gray with horny surface; fossiliferous (229)	25
Sandstone, thin bedded, bluish gray, weathering reddish gray; contains small lenses of limestone	2,690
Sandstone, steel gray, weathering rusty brown; thin beds	770
Limestone, gray, alternating with brown sandstone in thin beds	190
Sandstone, fine grained, dense, brownish gray, in beds 2 to 6 feet thick	1,400
Same, inclosing several beds of limestone 1 foot to 6 or rarely 10 feet thick	620
Sandstone, calcareous, laminated, becoming thicker bedded and firmer toward the top	780
Limestone, blue, fossiliferous (228), thin bedded, inclosing some thin layers of calcareous shale	80
Conglomerate, well-rounded chert pebbles 1 inch or less in diameter with interstices filled with coarsely granular silica	10
Sandstone, calcareous and in some beds argillaceous, bluish gray and steel gray, weathering buff	100
Conglomerate similar to that above described	210
	7,115

It seems most reasonable to consider the base of this lower conglomerate as the base of the Pennsylvanian series, but until other sections have been studied the determination can only be tentative. Below the conglomerate is 380 feet of fine-grained bluish-gray thin-bedded sandstone which rests upon 30 feet of chert including thin lenses and partings of shale. Between this and the valley floor is about 100 feet of material which affords smooth slopes and talus of intensely fractured dark-gray slate. Possibly the cherty formation that rests upon this slate is the basal member of the Pennsylvanian.

Three small lots of fossils assigned to the lower Pennsylvanian were collected in the Lost River Range about 50 miles east-northeast of the Muldoon section. Here, in the principal section examined, only 500 feet of Pennsylvanian beds, resting upon fossiliferous upper Mississippian limestone, are preserved from erosion. They form smooth grassy slopes broken only by two cliff-forming members, one 30 feet and the other 15 feet thick. The 30-foot member comprises alternating bands of limestone, chert, and sandstone and is about 250 feet above the base of a thin-bedded siliceous series that is very different in character from the underlying thick-bedded upper Mississippian limestone. Above it smooth slopes continue through 200 feet of beds to the second cliff-forming member, which is highly fossiliferous but otherwise similar in character to the lower one. This forms the crest of the divide.

The Pennsylvanian rocks here exposed appear to rest conformably upon the Mississippian beds, but in this section there is nothing closely comparable to the cherty conglomerate thought to represent the base of the Muldoon section. To harmonize these observations is one of the many problems suggested by the reconnaissance of the Mackay region.

AGE AND CORRELATION.

The determination of the series exposed in Muldoon Canyon as of Pennsylvanian age is based principally upon two lots of fossils, referred to in the detailed section:

No. 228.

Campophyllum sp.
Rhombopora sp.
Productus aff. P. gruennovaldti.
Productus aff. P. porrectus.
Productus aff. P. lineatus.
Ambocoelia sp.

No. 229.

Fusulina secalica.
Echinocrinus sp.
Batostomella sp.

Concerning these fossils George H. Girty, who identified them, says:

> Experience has shown that *Fusulina*, which occurs in lot 229, is a reliable index of the Pennsylvanian. Lot 228, although not perfectly diagnostic, also shows Pennsylvanian affinities, and collateral facts of lithology and stratigraphy also support a reference to the Pennsylvanian. This is clearly not a Madison fauna nor the upper Mississippian of near-by areas.

Three lots of fossils, referred to the Pennsylvanian by Mr. Girty, were collected in the Lost River range. These fossils, with the approximate location of the outcrops where they were collected, are listed below.

538. From massive blue limestone which forms the divide at head of Ramshorn Canyon:

Chaetetes milleporaceus.	Productus semireticulatus.
Zaphrentis sp.	Marginifera lasallensis? (may be Productus).

539. From thin-bedded, cherty, sandy limestone, 15 feet exposed on summit east of Moore:

Batostomella sp.	Productus symmetricus?
Productus semireticulatus.	Spirifer rockymontanus.
Productus cora.	Composita subtilita.

544. From limestone in first point east of Arco:

Batostomella sp.	Productus nebraskensis?
Productus semireticulatus.	

Concerning these three lots Mr. Girty says that "the collections are probably of lower Pennsylvanian age, though the faunas are not quite as varied and distinctive as might be desired."

The Pennsylvanian is widely distributed in areas to the north, east, and southeast, but in no reported section does it attain the thickness found in the vicinity of Muldoon. In southeastern Idaho and northern Utah the series is well developed, being represented by 2,400 feet of sandy limestones, calcareous sandstones, and quartzites of somewhat variable character.[1] To the north, in the Philipsburg quadrangle, Mont., the Pennsylvanian is represented by a quartzite member 400 feet thick and below it a shaly member from 50 to 600 feet thick.[2] In view of the apparent variation in the character of the series in different parts of the Mackay region this accordance with

[1] Richards, R. W., and Mansfield, G. R., The Bannock overthrust, a major fault in southeastern Idaho and northern Utah: Jour. Geology, vol. 20, No. 8, pp. 689-693, 1912.

[2] Emmons, W. H., and Calkins, F. C., op. cit., p. 67.

sections in near-by regions is perhaps as close, lithologically, as might be expected, but it seems quite certain that the Pennsylvanian formations, like the upper Mississippian, Devonian, and Ordovician, show a pronounced thickening in this part of Idaho.

MESOZOIC ROCKS.

GRANITIC INTRUSIONS.

GENERAL FEATURES.

An intrusive igneous mass crops out in the vicinity of White Knob, and a much larger one is exposed southwest of Copper Basin. The rock near White Knob has about the composition of a soda granite, but that southwest of Copper Basin, as suggested by the only two specimens collected from it, seems to range from quartz monzonite to normal granite. Both are batholithic intrusions, having transgressive contacts on all sides, and are believed to be outliers of the great granite batholith of Idaho that crops out to the west over a continuous area of more than 20,000 square miles.

WHITE KNOB BATHOLITH.

Distribution and form.—The eastern half of the White Knob intrusion was studied in considerable detail, and a few specimens from the other half indicate that it presents essentially the same relations and characteristics. The rock is well exposed in the vicinity of the Empire mine and along the canyon of Cliff Creek, where it is conspicuously sheeted and the partings in most places have a general north-south trend and stand almost vertical both parallel to the contact and at right angles to it. The limestone beds are not noticeably deformed by the igneous rock, which lies against them with extreme irregularity. In general, the area of the batholith increases with increased depth, but in the Empire workings the contact is almost vertical for 700 feet below the surface. On White Knob a great projection of the limestone extends over the igneous mass, which is a portion of the roof of the batholith about 1 square mile in area and 1,000 feet thick, and about its border the contact is very irregular. There are several protrusions of the limestone into the general area of the granite porphyry, many apophyses of granite porphyry into the limestone, and, particularly in the vicinity of the Empire mine, numerous engulfed blocks of limestone.

Petrography.—The rock of the batholith has a wide range in texture and hence in general appearance. Along the periphery a zone from a few feet to a few hundred feet in width is much finer grained than the main part of the mass, although it has essentially the same composition as the coarsely porphyritic part. In it the groundmass is microcrystalline and the feldspar and quartz phenocrysts are small and widely spaced.

The normal rock is a dark-gray granite porphyry containing phenocrysts of feldspar from a quarter to half an inch in length and rounded crystals of quartz about a quarter of an inch in diameter that stud rather thickly a groundmass composed of flecks of biotite and needles of hornblende along with considerable amounts of feldspar. Orthoclase is the most abundant feldspar, but albite, microcline, and oligoclase, one or all, occur in most of the thin sections. Quartz is next to orthoclase in amount, and much of it is embayed to an unusual extent. Micropegmatite is abundantly developed locally. Biotite is usually present in noteworthy amounts, and hornblende and diopside are not uncommon, although nowhere abundant. Titanite, magnetite, and apatite are present in most of the thin sections as accessories, and rutile occurs in some of them.

A complete analysis of the granite porphyry appears on page 61.

None of the rock seen in place can be considered a typical granite, because of its distinctly porphyritic texture. It is noteworthy, however, that specimens on the dump of the Darlington shaft, said to have come from a depth of 700 feet below the surface, are almost equigranular, as are also boulders along Cliff Creek. These few specimens that have a granitic texture and the considerable size of the intrusion suggest that the part now exposed is the marginal portion of a granite mass which is only slightly eroded—that is, that only the shell of the batholith is now visible.

The intense metamorphism that both accompanied and followed the invasion of the limestone series by this magma presents many features of particular interest, which are discussed elsewhere (p. 55).

GRANITE AREA SOUTHWEST OF COPPER BASIN.

Beyond the low timbered hills of lava rock west of Copper Basin rise precipitous slopes of light-gray color that contrast sharply with those of the other rock formations in the vicinity. Boulders along streams flowing from this area show that the rock is a gray granite of medium texture. For a distance of 6 or 8 miles eastward from the edge of the area mapped it forms the divide between streams that flow northward and those that flow southward. Westward it continues for several miles into the area of the Hailey quadrangle, where bold outcrops were observed about the head of Wildhorse Canyon.

Along its eastern margin the batholith has been cut extensively by the erosion which formed the large valley now occupied by the Tertiary lavas. East of these lavas, however, the granite again appears in the point of the second ridge north of the Starr Hope mine. Here it is a fine-grained medium-gray holocrystalline rock, made up of oligoclase, less orthoclase, some albite, quartz, hornblende, and biotite, with accessory magnetite, apatite, and zircon. Another specimen from the same locality is of closely similar appearance, but does not contain plagioclase. Thus it seems that the rock ranges in composition from quartz monzonite to granite, but it is believed that the granitic phase is predominant.

AGE OF THE BATHOLITHS.

The age of these large intrusive masses is not determinable from local evidence, but it seems quite reasonable to assume that they represent the same general period of intrusive activity as does the great central batholith of Idaho. The rocks of both regions are similar, bear the same general relation to the older mineral deposits, cut the youngest Paleozoic rocks of the region, and extend upward to the level of the Eocene erosion surface. The great Idaho batholith has been assigned, on fairly safe evidence, to the late Cretaceous or possibly to the early Eocene,[1] and the similar rocks in the Mackay region are believed to be of about the same age.

DIKE ROCKS.

DISTRIBUTION AND CHARACTER.

Dikes are meagerly developed in the Mackay region. In the vicinity of Muldoon several were observed, and locally about the border of the White Knob batholith they are abundant. In the southern end of the range east of Birch Creek a basic dike was observed in the Birch Creek mine, and two or three were seen in the mines of the Era district.

Near the Empire mine the dikes include trachyte porphyry, granite porphyry, and aplite; in the Muldoon district quartz diorite porphyry, granite porphyry, and aplite; in the Birch Creek mine basalt; and in the Era district andesite and possibly quartz diorite porphyry.

GRANITE PORPHYRY.

The granite porphyry, as developed in the vicinity of the Empire mine is a dense, dark-gray rock, made up of small phenocrysts of orthoclase and quartz, together with a little oligoclase and albite, set sparsely in a microcrystalline groundmass, in which, in most specimens, only flecks of biotite and hornblende can be identified. The rock occurs in dikes, of a maximum width of 100 feet or more, which are clearly offshoots from the main batholithic mass.

APLITE.

The narrow dikes of aplite in the vicinity of the Empire mine are of particular interest because they present perfect freshness in areas where the igneous rock which they traverse is completely changed to garnet-diopside-magnetite rock. This is interpreted (p. 75) to mean that the material which formed the aplite dikes escaped from the magma after the metamorphosing solutions were expelled. Similar aplite dikes occur sparingly in the Muldoon and Copper River districts. The rock is a fine-grained medium-gray to buff aggregate of idiomorphic orthoclase and considerable quartz. It contains a very little accessory apatite and here and there a fleck of biotite or a needle of hornblende.

QUARTZ DIORITE PORPHYRY.

Quartz diorite porphyry was not certainly identified, although two specimens of intensely altered material from the Drummond prospect are believed to represent this type of igneous rock, which in areas to the west is perhaps the most abundant dike material. In general appearance the rock is medium gray and made up of thickly spaced phenocrysts of feldspar and a little biotite in a minutely crystalline groundmass. Microscopic examination shows abundant sericite developed after feldspar, and chlorite after biotite. A few grains of quartz

[1] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, pp. 42-43, 1913.

occur in both sections, and as some of the feldspars are certainly oligoclase and others may be orthoclase the rock is either a quartz monzonite or a quartz diorite porphyry.

TRACHYTE PORPHYRY.

Trachyte porphyry was observed only in the workings of the Empire mine and others near by, where it is exceedingly abundant in the form of dikes that range from a few inches to perhaps 50 feet in width. These dikes can not be traced on the surface except in a few places because of their marked tendency to crumble into parts too small for identification. Even several hundred feet below the surface drifts which cross them are closely lagged, as within a few months the rock crumbles down in quantities sufficient to block a tunnel.

The trachyte porphyry is made up of large Carlsbad twins of orthoclase and locally medium-sized quartz and hornblende crystals embedded in a dark-gray felsitic groundmass. All the specimens examined microscopically show in the areas of orthoclase crystals and of the groundmass an earthy-looking field containing a little chlorite and felted aggregates of sericite.

These dikes cut across garnet-diopside rock and are hence younger than the metamorphism. They are traversed, however, by aplite dikes, as shown in an exposure north of the "big quarry" of the Empire mine.

CENOZOIC ROCKS.

ANDESITE ERUPTIVE ROCKS.

GENERAL RELATIONS.

The Eocene and Oligocene epochs, as suggested in the section on physiographic history (p. 19), seem to have been times of uninterrupted erosion, but in the Miocene epoch lavas flooded many of the larger valleys, forming great belts of andesite, rhyolite, and related lavas and tuffs. In places lakes formed behind lava dams and served as catchment basins for débris from adjacent uplands. (See Pl. V.)

DISTRIBUTION.

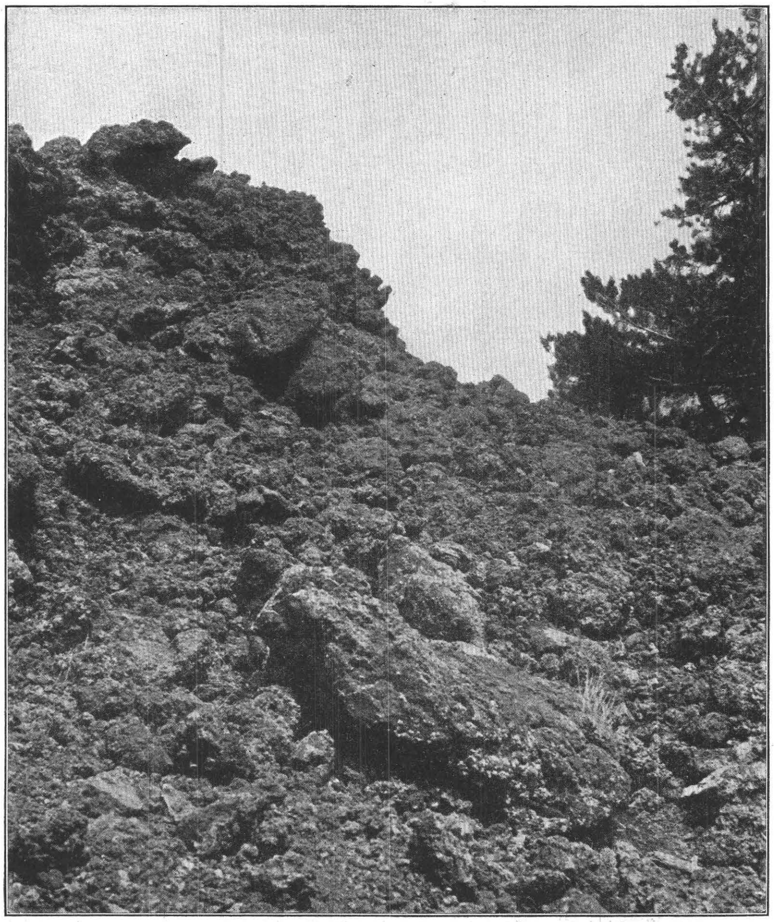
There are three principal belts of Miocene eruptive rocks in the region. One belt extends from the valley of Big Lost River, in the vicinity of Leslie, across the Lost River Range and northwestward along its northeast flank to a point well beyond the limits of the area mapped. Another belt crosses the same range in the vicinity of Arco and forms the divide at Arco Pass. The largest belt, however, lies south of the valley of Big Lost River. This area lacks the regularity in outline that characterizes the others, although it has a general trend to the southeast. From Copper Basin a broad belt leads northward across the summit toward the settlement of Chilly, another extends south, and a third passes over the divide and expands widely in the broad basin of upper Antelope Creek. This part of the general area connects with the Snake River plains, both north and south of Timber Mountain, and wide arms extend in the direction of Fish Creek, to the south, and of Big Lost River valley in the vicinity of Leslie, to the north.

The lavas reach from the level of Big Lost River valley, at an elevation of about 6,000 feet, to 9,000 feet on Warren Peak and to a comparable height south of White Knob. There seems to be no crustal warping or faulting to account for the differences in level, and as they occupy drainage lines, which presumably have fairly even floors, it is probably safe to assume that the difference between the elevations, or 3,000 feet, represents their minimum thickness. The distance to which they extend below the present drainage lines can not be determined, and the extent to which erosion has reduced their upper surface can be only approximated. It seems reasonable to believe, however, that in many places they accumulated to thicknesses much greater than 3,000 feet. The series forms smooth slopes, rounded summits, and low cliffs of dark-gray color, which locally give way to a yellowish red owing to the oxidation of iron-bearing minerals, or to a chalky white where considerable layers of tuff are included.

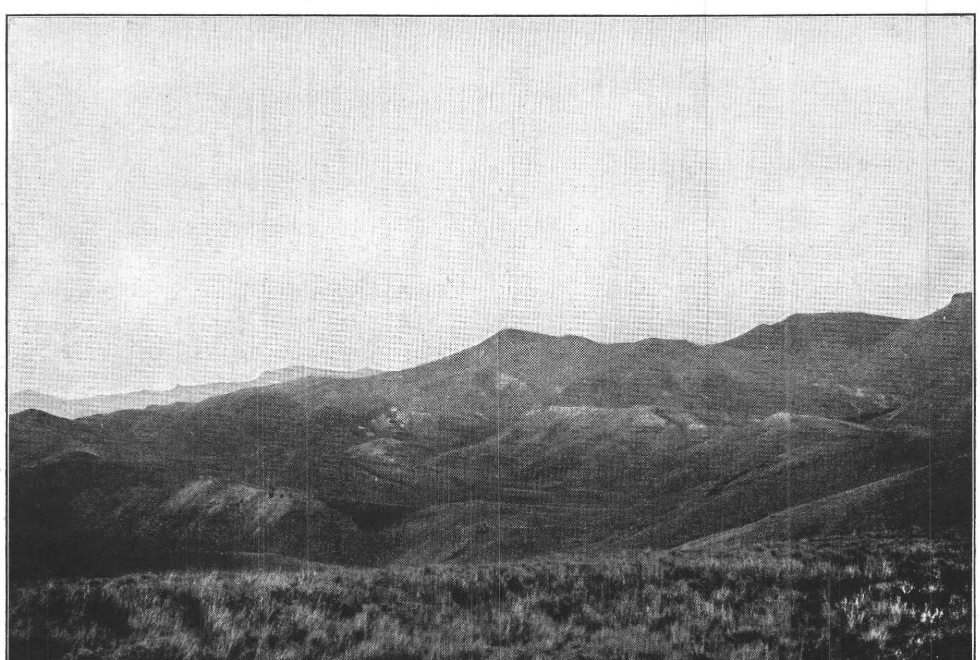
PETROGRAPHY.

Perhaps the most common type of rock in the series is andesite, although rhyolites, trachytes, latites, and related tuffs all occur in the area. Although the eruptive sequence is not known, it appears that in general the andesites are more abundant in the lower and the tuffs more abundant in the upper horizons.

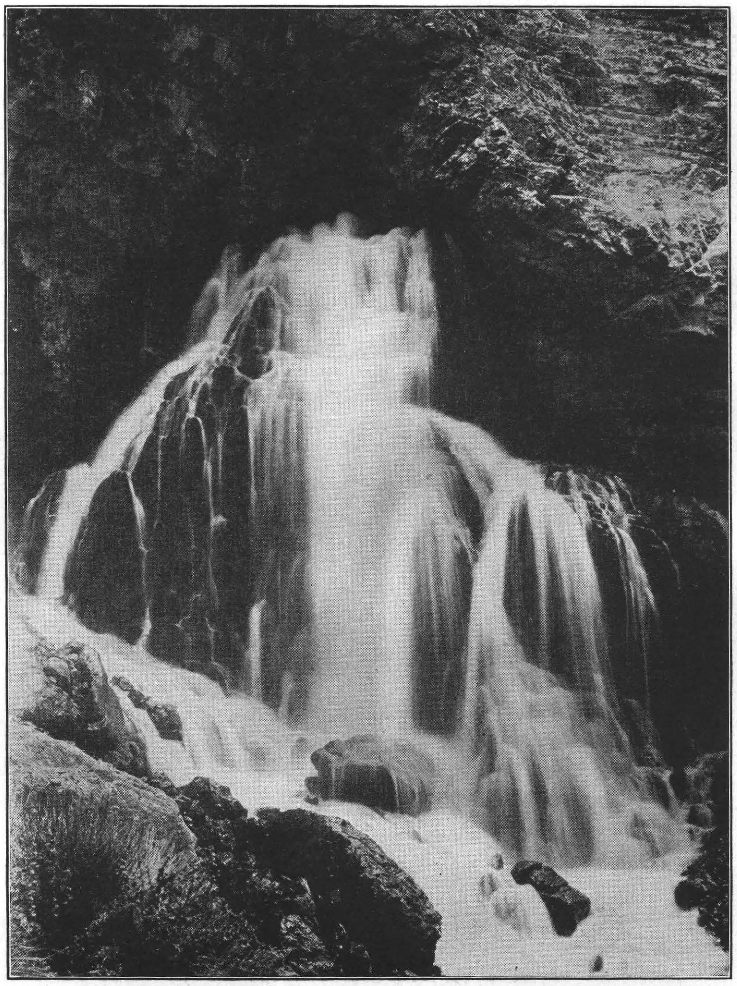
A specimen collected near Pass Creek summit and typical of that vicinity, is a grayish-black rock studded with many bright needles of hornblende. In it the phenocrysts exceed the groundmass slightly in area. The groundmass is microcrystalline and is composed principally of minute crystals of feldspar. The



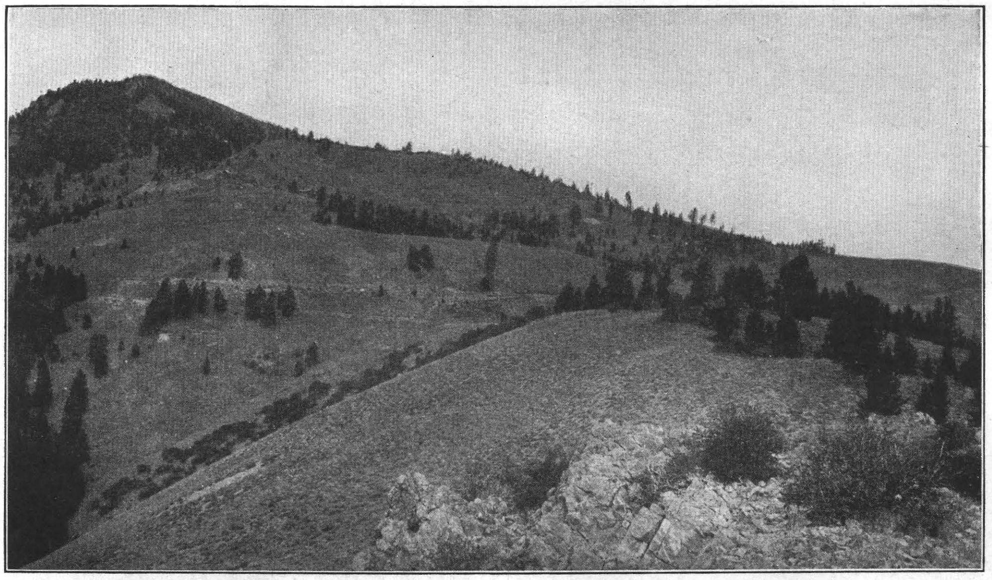
A. CHARACTERISTIC SURFACE OF LATEST FLOWS OF SNAKE RIVER BASALT, LAVA CREEK DISTRICT, IDAHO.



B. TYPICAL TOPOGRAPHY OF MIOCENE ERUPTIVE ROCKS, ERA DISTRICT, IDAHO.



A. BIG CLEAR CREEK SPRING, NEAR MACKAY, IDAHO.
Issues about 20 feet above the base of a high limestone cliff.



B. TOPOGRAPHY IN THE VICINITY OF THE UPPER ORE BODIES, EMPIRE MINE, ALDER CREEK DISTRICT, IDAHO.

phenocrysts comprise hornblende, oligoclase, andesine, a little biotite and much less magnetite and apatite. Another specimen from the same vicinity is pale lavender and contains noteworthy amounts both of hornblende and biotite, along with feldspar, in a fine-grained to glassy groundmass. The feldspars are approximately oligoclase-andesine in composition and exceed hornblende, which in turn is somewhat greater than biotite in amount. The area of the groundmass greatly exceeds that of the phenocrysts.

Rhyolite occurs in low exposures east of Arco. It is a light-gray rock that carries small crystals of feldspar, biotite, and quartz embedded in dense material, some of which shows flow lines. In the same vicinity there occurs a grayish-green rock, which consists of a fine-grained groundmass thickly studded with small crystals of feldspar. The feldspars are much more calcic than in most of the other specimens of the lava series, ranging from labradorite ($Ab_{40}An_{60}$) to bytownite ($Ab_{30}An_{70}$). There is much secondary chlorite in the slide and noteworthy amounts of augite. Magnetite and hornblende are accessory. The rock should probably be considered an olivine-free basalt.

In the vicinity of Era water-laid tuff is almost as abundant as andesite. A specimen from the St. Louis mine is composed of small angular and subangular fragments, the outlines of which are shown by rims of iron oxide surrounding a core of minute, diversely oriented quartz grains. There is much secondary pyrite as scattered crystals, and a little sericite. The rock is too altered for identification, but in the hand specimen it looks like a rhyolite tuff, as is also suggested by its resemblance to a specimen from the Hubb mine, in which there are many remnants of orthoclase.

Basalt was observed in intimate association with the Miocene lava series at only one locality—at a point about 13 miles due west from Clyde and at an elevation of 7,500 feet. The basalt here rests on andesite and is overlain by tuffaceous material, clearly showing that it is a part of the Miocene lava series. A thin section of the rock shows many crystals of augite and a few of olivine distributed in a groundmass of minute plagioclase laths.

Latite has not been recognized from microscopic examination. Experience with the same lava series in adjoining areas, however, has shown that chemical analysis is likely to reveal potassium oxide in much of the andesite-like material in amounts sufficient to necessitate the classification of the rock as latite. In these rocks the potash evidently occurs in the groundmass.[1]

AGE OF THE LAVAS AND TUFFS.

The lavas and tuffs above described are believed to be of Miocene age because of their relation to great valleys of erosion developed after the elevation of the Eocene erosion surface and because a long period of degradation intervened between their eruption and the extravasation of the Snake River basalt, commonly accepted as chiefly of Pliocene age.

DIKE ROCKS.

Narrow dikes of andesite were observed in the Era district and of basalt in the Birch Creek district. Both occur in areas of eruptive rocks similar to them in composition, and probably represent fissures along which the lavas rose. They are very much younger than the dikes previously described and are believed to be of Miocene and Pliocene age, respectively.

MIOCENE LACUSTRINE DEPOSITS.

DISTRIBUTION.

Lake beds, contemporaneous with the lava series, crop out in the vicinity of Pass Creek summit, and it is not improbable that similar deposits lie beneath the alluvium in the valleys of Birch Creek and Big Lost and Little Lost rivers, as suggested on page 21. Also in the vicinity of Era there are beautifully stratified beds of tuff that probably were deposited in a body of standing water. The beds near Pass Creek summit are exposed over an area which extends about 4 miles south and 10 miles north of Lookout Mountain and is perhaps 3 miles in average width. On the west the beds interfinger with andesite flows and on the east they rest against an eroded surface of older rocks, principally limestone.

CHARACTER AND THICKNESS.

About 2,000 feet of beds are exposed a short distance north of Pass Creek summit, where the formation strikes N. 30° W. and dips 35° E. The beds are tuffaceous throughout, but there are two layers, about 100 feet apart stratigraphically, of nearly clean tuff. The upper

[1] Umpleby, J. B., Some ore deposits in northwestern Custer County, Idaho: U. S. Geol. Survey Bull. 539, pp. 25-26, 1913.

layer forms a ledge 10 feet high; the lower one, perhaps 4 feet thick, occupies a saddle. Between them lie thin-bedded limy shales which have a particularly carbonaceous layer at the base. Below the lower layer of tuff lie thin-bedded shales and beds of limestone fragments; above the upper layer lie more shale beds, which characterize at least the next 1,000 feet of strata. The beds of coarser material differ markedly in composition from place to place, according as the adjacent upland is carved from limestone, shale, quartzite, or older lava flows.

COAL.

A prospect for coal, comprising a 40-foot incline shaft, has been opened in the lake beds at a point a short distance north of the Pass Creek divide. Here a few thin seams of coal, not aggregating over 4 or 5 inches in thickness, have been found in the 4-foot bed of carbonaceous shale that lies above the lower bed of tuff. The prospect has aroused local interest, which in view of the origin of the lake beds in a small basin bordered by precipitous slopes, must be considered as ill founded. It is exceedingly improbable that any workable bed of coal will be found in these lacustrine deposits.

AGE OF THE LAKE BEDS.

Determinable leaf remains were not found in the lake beds. They are, however, of essentially the same age as the lava series, which has already been assigned to the Miocene (p. 35), and they present the same geologic and physiographic relations as the similar beds in Lemhi Valley that yielded Miocene plant remains.

SNAKE RIVER BASALT.

GENERAL FEATURES.

Long after the extravasation and extensive erosion of the Miocene eruptive rocks basaltic lava flooded the Snake River plains and the lower ends of the three major valleys of the region. In general the flow probably came from fissures, but in many places it came from low volcanic cones, as at Cinder Buttes, southwest of Martin, described by Russell.[1] In the vicinity of Era and Martin, particularly along Lava Creek valley, numerous vents were formed rather high up on the mountain sides and fed small streams of lava, all but perhaps two of which never reached the foot of the slopes. These two united and formed a stream about 300 yards wide, which continued to the mouth of the valley, about 8 miles away, and there expanded on the plains, forming a thin covering over similar but much older sheets. Much of this lava stream preserves at the surface its glassy luster and the most minute details of surface structure. It is evidently of very recent origin and probably represents a dying phase of the activity which earlier found expression in the far more extensive flows that flooded the great valley of Snake River. In the vicinity of Arco the flows represent three distinct stages of eruption, separated by periods during which considerable layers of soil were formed.

I. C. Russell's description [2] of the phenomena presented by the Snake River basalt is so complete and admirable, however, that it is not deemed necessary to describe further the basalt flows in this report.

AGE OF THE BASALT.

The lavas of the plains flowed around the eroded base of Big Butte, which is composed of andesitic material similar to that of the older lava series. There was, therefore, a considerable lapse of time between the two periods of eruption. The later period of eruption seems, however, to have been of great duration, as suggested by Russell,[3] who says:

> Although the first-formed sheets of the Snake River lava are perhaps of the same age as the main mass of the Columbia River lava, by far the greater part of it is much younger. The latest outpourings of molten rock over the Snake River plains occurred probably within recent historic times and are perhaps not over 100 to 150 years old.

The great bulk of the Snake River basalt, however, appears from Russell's description to be contemporaneous with the Idaho formation, which has been assigned definitely to the Pliocene, on fossil evidence.[4]

GRAVEL BEDS AND ALLUVIUM.

Deposits of gravel and alluvium are widely distributed along the larger valleys, and thick accumulations of glacial débris occur locally in the higher mountains, particularly below

[1] Russell, I. C., Geology and water resources of the Snake River plains of Idaho: U. S. Geol. Survey Bull. 199, pp. 72–110, 1902.

[2] Idem, pp. 59–145.

[3] Idem, p. 61.

[4] Lindgren, Waldemar, and Drake, N. F., U. S. Geol. Survey Geol. Atlas, Nampa folio (No. 103), pp. 2–3, 1904.

the great cirques formed by alpine glaciers. The extensive valley deposits represent more than one kind of phenomena. The older deposits were possibly formed in pre-Quaternary time and may be due to special climatic conditions (see p. 21); those of intermediate age include both glacial moraines and outwash and the deposits of streams from the mountains whose velocity is checked abruptly when they reach the broad valley flats; and the most recent ones represent in large part material from the older deposits reworked by present-day streams. After the process was once well started perhaps as important a factor as any other in the deposition of material by streams tributary to the main arteries has been their loss in volume in crossing the broad flats of loosely consolidated débris.

Nowhere in the larger valleys do the streams flow on bedrock and in no place have they cut into the gravels to a depth greater than perhaps 50 feet. In the vicinity of Mackay the deposits are well exposed. Here Big Lost River occupies a shallow channel along the western side of an alluvial flat, perhaps one-half mile wide and about 40 feet lower than the main valley floor. The transition from the alluvial flat to the gravel terraces is abrupt and is characterized by excellent exposures of gravels of angular to rounded form, which in the main are rather firmly cemented by calcium carbonate. In many places they contain well-sorted sandy layers which separate others of coarser material, and locally cross-bedding is beautifully developed. Great alluvial fans of loosely assembled material rest on the comparatively undisturbed upper surface of these older deposits. One of these fans, which spreads conspicuously from the mouth of Big Clear Creek canyon appears, next to the mountain, to be at least 50 feet thick. It is not now building, however, for the creek, which heads in a great spring (Pl. VI, *A*), enters it in a channel possibly 60 feet deep. The deep trenching of this fan speaks unmistakably of a reversal of conditions of gradation, but it is not the only comparatively recent reversal. The great valleys were first excavated, which implies a long period of degradation; then they were the sites of extensive deposition or aggradation; and now, although the streams are almost in adjustment, their activity in the valley flats is on the side of erosion rather than of deposition. There are suggestions of still other reversals, but as the study of these phenomena was only incidental to other work the observations are too incomplete to serve as a basis of interpretation.

Glacial ice of the Pleistocene epoch covered most of the areas above 8,500 feet in elevation, and tongues of ice extended down the larger valleys to elevations of about 7,200 feet and in places on the north slopes to 6,800 feet. Deposits by the glaciers are nowhere particularly extensive, but probably many of the gravel beds adjacent to the mountains comprise material washed from the ice front. In a few of the canyons terminal and lateral moraines are characteristically developed, but their scarcity in view of the tremendous erosion accomplished by the ice is perhaps more noteworthy than their presence, as it may be considered rigorous proof that much of the valley gravel is of Pleistocene age. Nearly all the canyons join the main valleys as narrow trenches, which widen headward to broad, rounded troughs that lead upward to great cirque basins, the obvious source of vast quantities of débris.

EPITOME OF GEOLOGIC HISTORY.

The earlier geologic history of the Mackay region comprises a record of long-continued sedimentation, followed by regional metamorphism and erosion in pre-Cambrian time. With the beginning of the Paleozoic began another era of prolonged sedimentation, during which more than 20,000 feet of beds was laid down, apparently in angular conformity. The sediments differed greatly in composition from time to time. In the Cambrian (?) period they were composed principally of sand, although one formation of clay was deposited. The deposition of sand continued well into the Ordovician but ceased abruptly about midway of the period, and thick layers of magnesian limestone and dolomite accumulated throughout the remaining part of the Ordovician and again in the early part of the Devonian. After this came a long period during which beds of calcareous clay were spread out on the ocean floor, soon to be covered by later Devonian limestone and dolomite. In the Mississippian rather pure limestones were again laid down in formations of great thickness, but in the Pennsylvanian the sediments changed to a mixture of calcium carbonate, sand, and clay.

Some time after the last of these beds was deposited great dynamic movements developed folds whose limbs now commonly dip 45° away from northerly to northwesterly axes. This compression was so intense that many of the folds were overturned, and along the axes of some of them the beds broke and thrust faults resulted.

So far as the record is legible erosion was the dominant feature during the Mesozoic, but near the close of that era great volumes of magmatic material invaded the Paleozoic formations, locally causing intense metamorphism both at the time of intrusion and at a time long after the outer part of the magma had solidified. These invasions of magma may have accompanied the pronounced folding, which deformed the Paleozoic strata; at least their invasion is believed to have been expressed at the surface by a pronounced elevation, which during the Eocene was planed well toward the base-level of erosion for the region.

The Eocene surface of gentle topographic forms was soon elevated 8,000 to 9,000 feet, and broad, deep valleys were developed during the Oligocene. In the Miocene these valleys were flooded to depths well below the present drainage lines by andesitic and rhyolitic lavas, which interrupted the drainage and locally formed lakes behind lava dams. Never since that epoch has the region been so deeply trenched, although erosion was again dominant during the late Miocene and early Pliocene. Again in the Pliocene volcanic activity was rife, but this time only the valleys along the southeast margin of the region were flooded. The Pleistocene and possibly the late Pliocene embrace an epoch when destruction of the highlands exceeded erosion along the main arteries. Great beds of gravels formed in the larger valleys, and in these the streams of the present day are but slightly entrenched. Glacial ice covered the highlands in the Pleistocene and carved many of the features which now lend picturesqueness to the mountains.

DEFORMATION.

GENERAL FEATURES.

Three major periods of deformation are clearly recorded in the structural relations of the rocks within the Mackay region. Great crustal warpings took place near the close of the Algonkian, during the Mesozoic, and to a less extent in the late Tertiary. The period of most vigorous deformation seems to have been that which resulted in the compression of the Paleozoic strata into sharp folds before or during their invasion by the granitic magmas. The earliest deformation is recorded in the far greater crumpling and shattering of the Algonkian beds than that of similar near-by Cambrian (?) strata. In contrast to these more ancient deformations the Tertiary movements were not intense. They resulted in broad elevations, and only locally did they develop dips as steep as 35°.

The dominant structural axes of the region, which range from north and south to northwest and southeast, were determined during the middle period of deformation.

DEFORMATION OF THE PRE-CAMBRIAN ROCKS.

Pre-Cambrian rocks were observed only in the Lemhi Range, east of Clyde. Here they are probably separated from younger beds by a normal fault, so that the only basis for believing that they have suffered one more period of deformation than the Cambrian (?) rocks is their greater metamorphism. They consist of minutely crumpled and fractured shales and thin-bedded quartzites so deformed that bedding planes may be recognized only with great difficulty. In the Cambrian (?) strata, on the other hand, the bedding is well preserved, except along local axes of particular disturbance, as in the vicinity of the Wilbert mill in the Dome district. From this it seems that there must be a marked angular unconformity at the base of the Cambrian (?) strata in the Mackay region, but exposures favorable for its detection were not found.

DEFORMATION OF THE PALEOZOIC ROCKS.

The post-Pennsylvanian pre-Tertiary deformation, by far the most conspicuous of any which is recorded, affected all parts of the Mackay region. Beds which seem to have been undisturbed throughout the entire Paleozoic era were compressed into northerly trending folds, many of which were overturned and faulted. The compressional stresses thus effective were followed by tensional stresses, which resulted in gravity faults along fractures, some of which were developed during the earlier movements.

The zone of most pronounced bending of the strata seems to have been along the Lost River Range from the vicinity of Moore north-northwest obliquely across the range to a point near the head of Pahsimeroi River. One part of it is well exposed in Ramshorn Canyon and west of Pass Creek summit. In Ramshorn Canyon the beds rise gently from the valley of Big Lost River toward the summit of the range, attaining a height of 3,500 feet above the canyon floor at a point about a mile from its mouth. Here they bend down sharply and stand vertical for a distance of 750 feet, beyond which they again assume a westerly dip of about 30°, which continues to another zone of vertical beds about equal in width to the other. Many of the vertical beds are separated by layers of gouge, indicating considerable movement along these layers. A thick layer of shale, which extends nearly to the top of the cliff west of the first zone of vertical beds, does not appear east of it, showing that the abrupt downbending here is more than 2,000 feet in extent. No readily recognized bed was observed which could be used in determining the extent of the upper fold, but it seems to be fully as large as the lower. The two bends approach each other toward the north and cross Joggle and Elbow canyons as one fold, which beyond, to the north, is concealed by the eruptive rocks of Pass Creek basin. Farther on it reappears as a broad zone of most intricately folded beds, where many exposures show S-shaped bends. East of Mackay a line of vertical beds, which joins the fold at an acute angle, leaves the valley and passes northward between Mount McCaleb and the summit. In the general zone of compressed beds there are a great many small normal faults which traverse the previously folded strata, and in places along the vertical beds faulting opposite in throw to the movements that accompanied the folding is clearly recorded in shearing planes developed in the gouge.

In the Lemhi Range structural features were worked out only in the vicinity of the Wilbert mine. Here, as shown in Plate XXI (p. 116), an overturned fold, accompanied by a thrust fault, has been followed by normal faults. The relations are somewhat fully described in the section on the Dome district (pp. 113–118).

The age of this general period of profound compression stresses followed by tensional stresses can not be definitely determined from the information now available. It certainly followed the Pennsylvanian, for strata of that age are involved, and preceded in the main the solidification of the granitic magmas, which are believed to be of late Cretaceous age. The general folding which developed such sharp flexures locally and threw all the Paleozoic beds into folds whose average dips are probably greater than 40° must have caused a profound elevation of the surface; but as has been suggested elsewhere [1] there is no direct evidence of profound elevation until the late Cretaceous or early Eocene, when the granite is believed to have risen beneath the surface. There is, therefore, some reason for thinking that the great deformation of the Paleozoic formations took place at about the close of the Mesozoic, and that it and the granitic intrusion of central Idaho are genetically related. There is about equal reason for surmising (1) that the granitic intrusion gave rise to the compressional stresses which caused the folding, or (2) that the profound crustal movements which resulted in the folding gave rise to the granitic magma. At any rate it is believed that the probable genetic relation betwen the deformation of this period and the granitic intrusion will present problems of profound interest to future students of the geology of east-central Idaho. It is quite possible that these studies will involve the origin of the Livingston, Philipsburg, and Bannock overthrusts.

DEFORMATION OF THE TERTIARY ROCKS.

No evidence of deformation in the Mackay region after the extravasation of the Snake River basalt has been recognized, but the Miocene lake beds and lavas have been tilted and faulted. In the area of lacustrine deposits north of Pass Creek summit the beds are nearly horizontal in most places, but locally they are inclined as much as 35°. In the mines at Era the stratified tuff has also been tilted locally to inclinations as great as 15°. The post-Miocene tilting in this region seems to have been along axes nearly parallel to the folds which involve the Paleozoic beds, but observations to the

[1] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, p. 43, 1913.

north, in Lemhi County, show that the folds of this epoch have no constant direction. It is noteworthy also that in every locality observed the dips change direction within short distances.

Normal faulting has taken place during this epoch of disturbance, as is shown in the St. Louis mine, where stratified tuff is faulted against eruptive rocks; but this phenomenon, like the other deformation, does not seem to be quantitatively important.

METAMORPHISM.

CLASSES.

The rocks of the area exhibit two great classes of metamorphism: (1) Dynamic metamorphism, caused by crustal stresses, and (2) igneous metamorphism, caused by magmatic injections. The regional metamorphism was very general in its effect, transforming all the pre-Cambrian rocks to products which were derived entirely from the original minerals of the rocks; but the igneous metamorphism was a local phenomenon dependent both upon emanations from the invading magma and the structure and composition of the invaded rocks. This class may be divided into (*a*) metamorphism at the time of intrusion by recrystallization of material already present, and (*b*) metasomatism subsequent to the intrusion, in which vast quantities of material contributed by the magma played a part. It may also be divided into endomorphism and exomorphism, according as the transformation took place in the peripheral zone of the igneous rock or in the adjacent sedimentary rock.

DYNAMIC METAMORPHISM.

The pre-Cambrian rocks exposed in the Lemhi Range comprise schists, slates, and quartzites, all of which underwent extensive molecular rearrangement during the development of a marked schistosity not common in the younger formations. The characteristics of this transformation were not investigated, but the evidence of regional metamorphism before the beginning of the Cambrian period is clear.

IGNEOUS METAMORPHISM.

The igneous metamorphism is discussed in detail in the section on contact deposits, and the only object at present is to throw in relief its more important features and some of the general conclusions deduced from evidence presented on pages 55–58.

Igneous metamorphism was studied with care only in connection with the White Knob batholith, although from the observations near Muldoon it seems quite probable that contact silicates were formed to a minor extent also by the batholithic intrusion southwest of Copper Basin.

The phenomena at Mackay include the transformation of limestone into marble and garnet rock and the transformation of the igneous rock itself into garnet rock. The most notable marmarization is the metamorphism of a great segment of a roof of limestone into the marble that comprises White Knob. This marble mass, which is about 1,000 feet thick and 1 square mile in area, is quite uniformly metamorphosed throughout and exhibits a very meager development of all minerals except calcite. It is believed that at the time of its metamorphism physicochemical conditions were essentially uniform throughout its extent, and therefore that the solutions were fed to it equally at all points of contact with the magma.

Contrasted to this phenomenon is a later one that is characterized by solutions of very different composition which escaped from the batholith through fractures in its outer solid shell. These solutions developed tabular masses of garnet-diopside-magnetite rock, which cut as veins across the marble of White Knob. At this time also engulfed blocks of limestone and adjacent parts of the inclosing igneous rock were transformed to masses of lime silicates by solutions which escaped through fissures and along joints in the solidified shell of the batholith. As this metamorphism was unquestionably accomplished after the solidification of the incasing igneous rock, it is easy to prove the fundamental proposition that the derived rock occupies the same space as the original rock. From analyses and gravity determinations of the original and derived rock it is therefore possible to compute with a reasonable order of accuracy the gain or loss in each constituent. It is found that iron, silica, and alumina have been added in large amounts and that most of the carbon dioxide and a little of the calcium oxide have been expelled. (See fig. 9, p. 58.) Proof is presented for the conclusion that the magma not only caused the transformation but that it supplied in full amount the constituents added during the metamorphism.

ORE DEPOSITS.

GENERAL FEATURES.

DISTRIBUTION.

The striking feature in the distribution of the known ore deposits in the Mackay region is their absence from the Lost River Range and their wide occurrence elsewhere. The range comprises a high mountainous belt, about 15 miles in average width, which extends entirely across the area in a northwest course. It presents exceptional exposures to the prospector and is more frequently traveled than other parts of the mountainous region; trails extend into it in many places from the thickly settled valleys which border it on both sides, and two wagon roads cross it. It seems inevitable that if ore deposits were as widely distributed here as elsewhere in the region some of them would have been found. To the northeast along the Lemhi Range, and along the mountain slope which borders Birch Creek valley beyond, mines have been opened at widely separated localities, and prospects are even more widely distributed. To the southwest ore deposits are also known at many places in the mountainous and comparatively inaccessible country.

GEOLOGIC RELATIONS.

The distribution of the deposits is not related to the type or structure of rock at the surface. In the Lost River Range Miocene eruptive rocks similar in structure and composition to those of the Era and Lava Creek districts are widely distributed, but ores occur in these rocks in the Era and Lava Creek districts and are absent in the Lost River Range. In this range there is also Paleozoic limestone of the same character and age as the limestone inclosing ore deposits in the Skull Canyon district, quartzite like that of the Dome district, and calcareous slates like those of Antelope district. Granitic rocks are absent from the Lost River Range, but they are also absent from that part of the Lemhi Range within the area mapped and from the range east of Birch Creek valley, although in the Birch Creek mine effects suggesting contact metamorphism were observed. In the southwestern part of the region several of the deposits are definitely related to igneous contacts, and it is certain that a granite magma supplied the material of the ores in the Alder Creek district at least. From this it is an easy step to the conclusion that all the deposits in the southwestern part of the area, except the late Tertiary veins, are related to an underlying granite mass which crops out only locally. By analogy and because the presence of ore is not dependent on the composition or structure of the rocks appearing at the surface, it is believed that an igneous mass underlies the Lemhi Range and extends eastward beneath Birch Creek valley and the mountain range beyond. (See discussion of genesis.)

CHARACTER AND SPECIAL FEATURES OF THE DEPOSITS.

The deposits of the Mackay region include contact deposits and veins. The contact deposits are masses of irregular shape, the most productive of which lie within the intrusive rock and represent the metamorphism of engulfed blocks of limestone and adjacent parts of the igneous mass; thus both endomorphic and exomorphic phenomena are represented. The veins represent two periods of mineralization, and, with the exception of one or two whose age is somewhat doubtful, may be definitely grouped as pre-Oligocene and post-Oligocene. The pre-Oligocene deposits may be further subdivided according as they are inclosed in quartzite, limestone, or granite porphyry, but the post-Oligocene deposits occur entirely in areas of eruptive rock—andesites, rhyolites, and related tuffs. The earlier veins include copper, lead-silver, and tungsten deposits; the latter are worked primarily for silver and associated lead.

In all the deposits replacement phenomena is a dominant feature, and indeed no vein is known in the region which, throughout its extent, is typically a fissure filling.

The contact deposits of the Alder Creek district are of particular interest because their relations show clearly that the granite magma supplied large quantities of iron, alumina, and silica to the contact rocks, in addition to constituents to the sulphide minerals, and that it did so after the outer few hundred feet of the magmatic mass had solidified. It is believed also that here there were two stages of metamorphism, one at the moment of intrusion and one subsequent to the fracturing of the solid shell of the magma. Of the second stage there can be no reasonable doubt.

The deposits of the Wilbert mine in the Dome district contain important bodies of plumbiferous quartzite, a type of lead ore which so far as the writer is aware has not been described from any other locality. The ore minerals occur as minute grains disseminated in quartzite, giving the ore a pepper-and-salt appearance (see Pl. XIX, *B*, p. 82), although the relative amounts of the light and dark grains are very different in different places and locally within distances of a few inches. A conspicuous and noteworthy feature of these deposits is the abundance of the oxides of iron and manganese, which have impregnated the wall rock for many feet beyond the limits of the ore bodies. The occurrence of these oxides, which are oxidation products from some primary metasomatic mineral, possibly siderite, is in every particular comparable to the occurrence of the lead minerals in the disseminated ore. Both seem to have replaced a siliceous cement in the quartzite and in places the quartz grains themselves.

Another noteworthy feature of the ores of the region is the occurrence of wurtzite in the post-Oligocene veins. This mineral is believed to form only in the presence of acid solutions and has previously been described, except from Beaver County, Utah,[1] only as a product of descending solutions. Here, however, it is unmistakably a primary mineral, none of the observed features of the deposits, except its presence, suggesting primary acidic solutions. Calcite is locally abundant in the gangue; and sericite, indicating the presence of potash, is extensively developed in the wall rock. These deposits are also somewhat exceptional, because the silver occurs in argentiferous galena associated with zinc sulphide, whereas in all the other late Tertiary veins in Idaho, and in most places elsewhere, base metals, if present at all, are accessory.

CLASSIFICATION OF THE DEPOSITS.

The classification of the ore deposits of any large area is one of the most perplexing problems that confront the geologist writing an economic report for the general reader. A classification to be most useful to the miner, the metallurgist, and the average investor in mining properties must take into careful account the substance and form of the ore bodies. Yet such a grouping of the deposits of most large areas leads to a treatment that fails to emphasize the broad physical and chemical relations which should be considered in order that each regional report may contribute to the permanent advance of the science and to its ultimate maximum usefulness to the mining industry. The most important problem in the study of ore deposits is their genesis, for a knowledge of the genesis of different types of deposits and their consequent characteristics is vitally necessary in their economical exploitation. A genetic classification, because it contributes most to our general knowledge of ore deposits, is clearly most valuable, but to follow it closely in a report where but few of the general types of deposits are represented eliminates subdivisions which otherwise might well be made.

In the classification followed here the grouping is first by age, second by genesis, third by substance, and fourth by kind of wall rock. The major grouping might have been according to depth of formation instead of by age, the younger deposits being formed nearer to the surface, but there is so little local evidence on this point that age is considered to be more satisfactory.

PRE-OLIGOCENE ORE DEPOSITS.

CONTACT DEPOSITS.

DISTRIBUTION.

Contact-metamorphic replacement deposits of copper and a little lead occur in Alder Creek (Mackay), Copper Basin, and to a very minor extent in Muldoon district. The deposits of the Alder Creek district have been extensively explored to a depth of about 700 feet, and ore has been extracted in many places over an area of about a square mile. The Copper Basin deposits, as now known, are confined to a much smaller area and far less extensively developed, although the promise of ore in depth is here at least equally encouraging. The deposits of these two areas were discovered about the same time, and the differences in development are largely the result of the greater diffi-

[1] Butler, B. S., and Schaller, W. T., Some minerals from Beaver County, Utah: Am. Jour. Sci., 4th ser., vol. 32, p. 420, 1911.

culty of access to Copper Basin, which lies beyond the range of mountains that borders the valley of Big Lost River on the southwest. The Alder Creek deposits may be reached from Mackay by a short railroad that is owned by the mining company. In another part of this paper (p. 106) appear notes on the Muldoon deposits by E. H. Finch.

GEOLOGIC RELATIONS.

AREAS CONSIDERED.

The rock formations of the area in which the principal contact deposits occur comprise a belt about 6 miles wide, composed of Paleozoic limestones, shales, sandstones, and their metamorphic equivalents, which extends from the valley of Big Lost River above Mackay southeastward across the mountain range to Copper Basin, a distance of 12 miles. Tertiary eruptive rocks, principally andesite, border the belt on the northwest and on the southeast. Granite porphyry, to which the ore deposits are genetically related, cuts through it in the east-central part and crops out over an irregular area of perhaps 10 square miles.

Near Mackay the copper ores occur principally within the area of the granite porphyry, and blocks of limestone engulfed in it determine the centers of metamorphism; but in Copper Basin the lime silicate ores occur in the sedimentary rocks adjacent to narrow aplite dikes, which are probably differentiates from a mass of the granite porphyry not yet exposed by erosion. These deposits lie about 5 miles southwest of the area of granite porphyry.

PALEOZOIC BEDS.

The Paleozoic rocks in the vicinity of the Mackay deposits comprise a monotonous succession of massive and semimassive blue limestone beds, rather pure above but containing much chert in the lower members. The beds here are sharply folded and the dips are generally greater than 45°. Their most common strike is N. 10°–20° W., and the dips are 50°–80° W., or toward the igneous contact. Variations both in strike and dip are so numerous and sharp that, though important faults within the limestone were not recognized, their presence is not improbable.

The total thickness of the beds in the immediate vicinity of the deposits is somewhat uncertain, because the absence of faulting was not definitely determined. A traverse down the ridge which extends to the northeast from the whim shaft of the Empire group suggests the presence of at least 4,000 feet of limestone beds, in the middle and upper members of which fossils of upper Mississippian age were collected.

In the vicinity of the Copper Basin deposits the beds include clear white fine-grained quartzite inclosing layers of black quartzite, above which lie beds of siliceous and calcareous shale and magnesian limestone.

The mountainous area between the Mackay and the Copper Basin exposures was not visited, but not improbably beds of Ordovician and Devonian ages, corresponding to the section measured in Elbow Canyon northeast of Mackay, occur within it.

GRANITE PORPHYRY.

The granite porphyry as exposed at the surface over an irregular area of perhaps 10 square miles is for the most part a distinctly porphyritic rock. In most places it presents steep slopes which terminate in high peaks, but locally along the margin it is even less resistant to erosion than the adjacent limestone. Thus, in the vicinity of the Mackay mines the gentle slopes extending back a thousand feet or so from the contact offer some suggestion that the marginal facies is a separate intrusion, a view, however, which is made entirely untenable by other direct observations.

The normal granite porphyry as seen in the hand specimen is a dark-gray rock carrying phenocrysts of feldspar from one-quarter to one-half inch in length and rounded crystals of quartz about one-quarter of an inch in diameter. These crystals of feldspar and quartz stud rather thickly a granular groundmass composed of flecks of biotite and needles of hornblende, together with much feldspar. As seen in thin section, orthoclase is the most abundant feldspar, though albite, microcline, and oligoclase, one or all, occur in most of the slides. Quartz, which is far less abundant than feldspar, exceeds biotite in amount. Hornblende and diopside, though nowhere abundant, differ in amount from place to place. Titanite, magnetite, and apatite are persistent accessories, and rutile is not uncommon. A grain of fluorite was observed in each of two sections. The quartz crystals are more uniformly and extensively embayed than in most of the igneous rocks of east-central Idaho, and locally micropegmatite is exceptionally abundant.

Near the contact the rock in most places is essentially of the same composition as the main body, though here the groundmass is microcrystalline and the feldspar and quartz phenocrysts are much more widely spaced and are smaller. This facies of the rock merges by imperceptible gradations of texture into the normal granite porphyry, with which it agrees closely in composition. Contact effects clearly have been caused by both the marginal facies and the normal granite porphyry; the most notable metamorphism by the porphyry being the transformation of the great mass of blue limestone to white marble on White Knob and its local garnetization, and by the marginal phase, the development of the garnet shoots in the Empire mine and in the Copper Bullion tunnel, whose effects are described in the discussion of the metamorphic phenomena (p. 45).

The width of this marginal zone of finer-textured rock is widely different in different places along the border of the intrusion. In the vicinity of the Empire mine it is 2,000 feet wide, but in the canyon of Cliff Creek it is not more than 10 feet in width. It also is narrow where the granite porphyry extends beneath the great marble mountain of White Knob.

DIKE ROCKS.

Three distinct periods of intrusion are represented by the dikes of the Mackay area. The oldest dikes are offshoots from the granite porphyry mass. The youngest, similar in mineral composition but containing less quartz and large phenocrysts, many of which are Carlsbad twins of orthoclase, is designated trachyte porphyry. Aplite dikes are intermediate in age between these two but are not abundant in those parts of the area examined. They were observed near the "big quarry" of the Empire mine and on the ridge northwest of the Copper Bullion tunnel of the same mine. Aplite dikes occur also in the vicinity of the Reed & Davidson mine in Copper Basin.

ERUPTIVE ROCKS.

The lavas of this area were poured forth long after the ore deposits had been formed, and, as they are well removed from known deposits of ore, will not be mentioned further in this connection. For a description of them and their relations see pages 34–35.

COPPER DEPOSITS.

AREAS CONSIDERED.

The contact copper deposits near Mackay were studied in considerable detail, as the several thousand feet of accessible workings here made fairly comprehensive observations possible. The Copper Basin deposits, on the other hand, are poorly exposed at the surface, and comparatively little development work has been accomplished. Then, too, they occur entirely in the sedimentary rocks, well removed from the known granite porphyry mass, and thus afford much less encouragement for the fruitful study of contact phenomena than the Mackay deposits, where the geologic relations are exceptionally favorable.

A special topographic and geologic map (Pl. VII, in pocket) was made of an area of nearly 4 square miles in the vicinity of the Empire mine. Beyond this area, however, detailed observations were made in the vicinity of the Champion group and of White Knob.

The following discussion has to do almost entirely with the Mackay deposits.

These deposits are of particular interest, because the ore bodies occur well within the granite porphyry mass; the principal metamorphism is later than the solidification of that part of the porphyry inclosing the ore shoots; engulfed blocks of limestone determined the centers of metamorphism; the garnet rock is derived both from granite porphyry and from limestone; and the magma clearly supplied great quantities of iron, alumina, and silica to the contact rock in addition to the constituents of the ore minerals.

The deposits were described in 1907 in a joint paper based on the field work of C. G. Gunther and the laboratory studies of J. F. Kemp.[1] These authors discuss at some length the contact metamorphism which characterizes the deposits. As a result of differences in field observations the present studies have led to some conclusions fundamentally different from those of the earlier writers. Their pioneer work, however, has been of great assistance in

[1] Kemp, J. F., and Gunther, C. G., The White Knob copper deposits, Mackay, Idaho: Am. Inst. Min. Eng. Trans., vol. 38, pp. 269–296, 1908.

the present investigation, and their analyses and descriptions of special features have been freely drawn upon. The present writer differs from them in believing (1) that the "quartz porphyry" is unquestionably a marginal phase of the "granite," which is a granite porphyry and instead of being the "fundamental rock of the district" is of late Cretaceous age; (2) that the garnetization took place after the consolidation of at least the outer few hundred feet of the magma, rather than while it was still viscous; and (3) that the engulfed blocks of limestone determined the centers of metamorphism.

DISTRIBUTION OF THE ORE BODIES.

The ore bodies, unlike those of most contact-metamorphic replacement deposits, occur within the main igneous mass, well back from its border. Most of the production has come from shoots of ore situated from 100 to 800 feet out in the granite porphyry, and two carloads were obtained from an ore body situated 1,200 feet back from the main igneous contact. No deposits of proved importance occur in the main limestone area. (See Pl. VIII, in pocket.)

The ore bodies, however, are in several places associated with great blocks of limestone engulfed in the igneous rock. (See Pl. IX, *B*.) The shoot of ore farthest within the igneous pass occurs on the east end of a block of limestone which crops out over an area about 650 feet from east to west by 200 feet from north to south. Each of the stopes from the Copper Bullion tunnel is bordered on one side either by limestone or its common equivalent, white marble, and on the other either by garnet rock or by granite porphyry. Limestone forms one end of the north stope above the Alberta tunnel on several floors (figs. 3, p. 46, and 5, p. 47) and garnet rock or locally granite porphyry forms the other. In the north tunnel the stope near the portal is bordered first by white marble on the left and granite porphyry on the right, but the garnet rock appears on both sides beyond a point 205 feet in. In the south group of stopes above the Alberta tunnel limestone is absent altogether, but even here the garnet rock locally has a faint stratiform appearance which suggests the bedding of limestone not completely metamorphosed.

Garnet rock accompanies all the important ore bodies and in most of the primary ore this mineral is the dominant constituent. The ore shoots are almost invariably bordered on one side, and in many places are completely surrounded, by garnet rock. Section B–B′ in Plate I (in pocket), though of necessity generalized in this particular, illustrates the common relation of the shoots of ore to those of garnet rock. Wherever it is possible to make a comparison of the regularity in outline of the ore body and the adjacent mass of garnet rock, it appears quite generally true that the outline of the garnet rock is the more regular.

The apparently heterogeneous distribution of the ore bodies is perhaps the most striking characteristic of these deposits, yet careful observation brings out two very persistent relations: (1) The margins of included limestone blocks are intensely mineralized in several places, as is clearly illustrated by all the larger stopes in the Copper Bullion tunnel (fig. 4); and (2) the ore bodies for 400 feet above the Alberta tunnel (fig. 2) are very definitely related to a fissure which strikes N. 20°–30° E. and dips 50°–60° SE. The fissure may be traced by a pronounced gouge wherever it traverses the granite porphyry, but within the area of garnet rock it is not discernible in many places, and within the ore bodies it is entirely obliterated in the lower stopes in the north end of the mine. In the south end of the mine, however, it appears as a smooth crack accompanied by a little selvage, interpreted as postmineral movement along a premineral fault. The later fault movement has not been sufficiently great, however, to appreciably offset the ore. This relation is shown by figures 3 and 4, which illustrate the relation of different bodies to the same fault in the north shoot. In the Copper Bullion tunnel the ore shoots do not appear to be related to any such dominant feature, although details of structure definitely bespeak the influence of joints in directing the movement of the solutions and in shaping the resulting deposits. Figure 4 illustrates the influence of joints in shaping the ore bodies in granite porphyry.

CHARACTERISTICS OF THE ORE BODIES.

The ore bodies differ greatly in size and even more in shape. Three principal groups of ore shoots are recognized, one in the Copper Bullion tunnel and two above the Alberta tunnel, each being made up of branching arms which commonly diverge upward but in places unite on higher levels. (See Pl. VIII for mine map, in pocket.) Most of the stopes are circular or elliptical in plan, and most of them pitch to

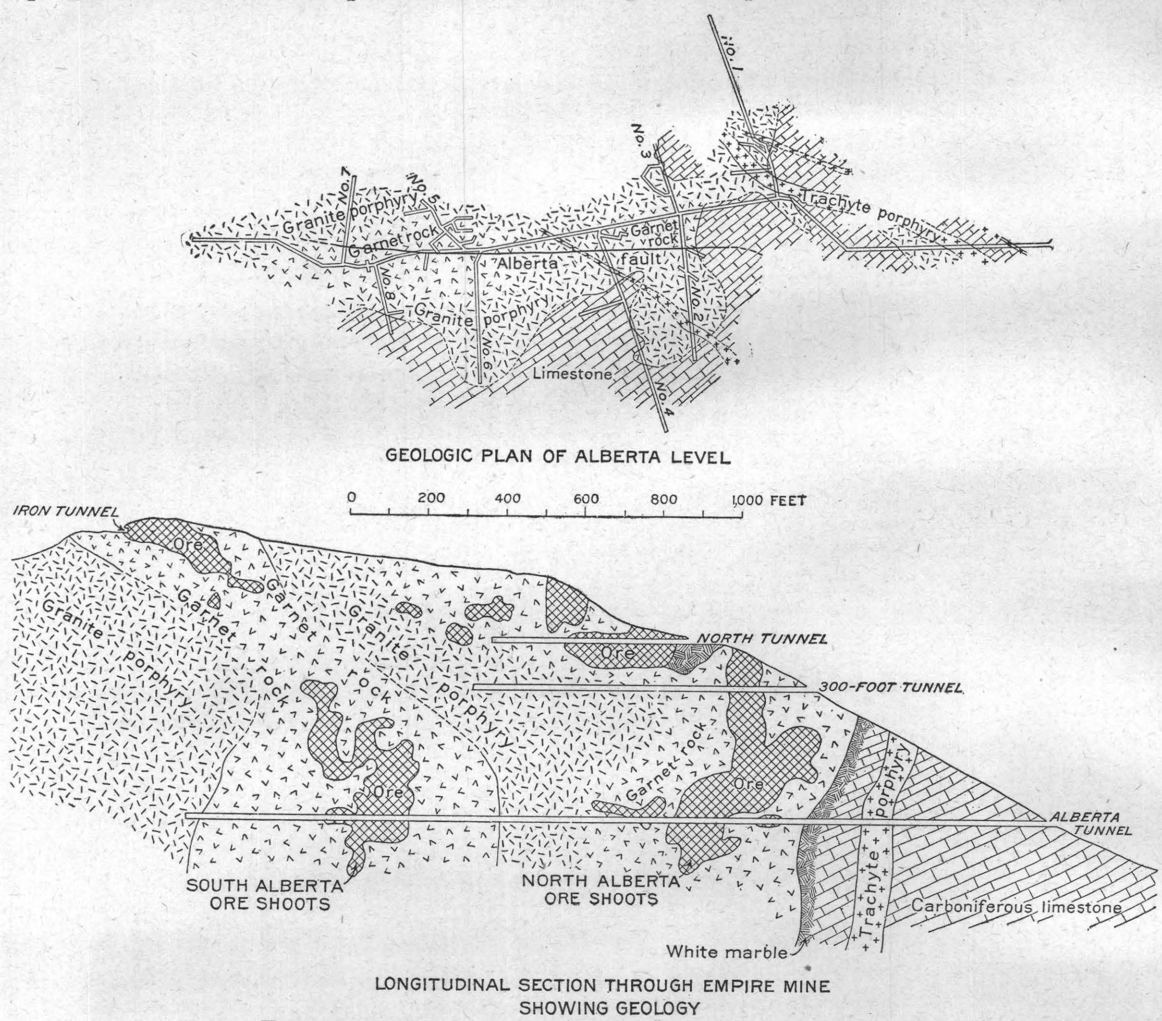


FIGURE 2.—Geologic plan and longitudinal section, Empire mine. Section somewhat generalized.

the southeast, though exceptions are numerous and striking. The greatest known vertical range of an ore body is from a point a few feet above tunnel No. 300 down to the 850-foot level. The shoot narrows to a few feet between the 500-foot and 700-foot levels, but above it has an average floor area of perhaps 3,000 square feet and below of 1,500 or 2,000 square feet. On the 450-foot level this composite shoot consists of the stope shown in figure 3 and one 24 by 18 feet situated 50 feet back in the hanging wall. Eastward and above, a garnet zone separates two stopes (fig. 5). On the 500-foot level there are three stopes, the same one shown in figure 2, there somewhat larger, and two chimneys or pipes, which lead off into the footwall. One of these chimneys is about 7 feet in diameter and the other is 7 by 14 feet in area. The south shoot is similarly irregular

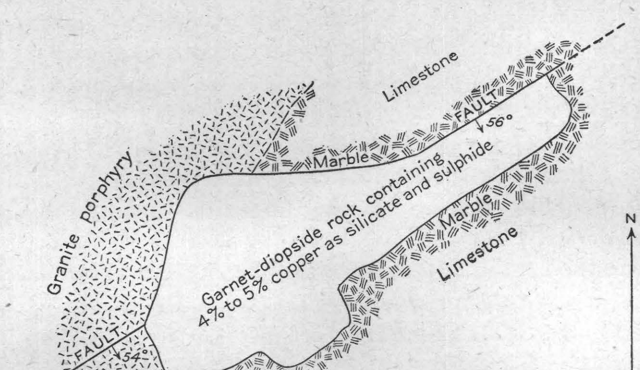


FIGURE 3.—Plan of stope on 450-foot level, north Alberta shoot, Empire mine. Shows premineral fault, sealed by ore body.

in shape; in it the large ore body that was opened immediately above the tunnel level splits within a few feet into east and west shoots. The east shoot dies out within a hundred feet, but the west shoot splits into four parts, the southernmost alone continuing to the 300-foot level. The remarkable "pipes" or "flues" described by Kemp and Gunther and verified by Ralph Osborn, the superintendent, occur on the ninth floor of the east

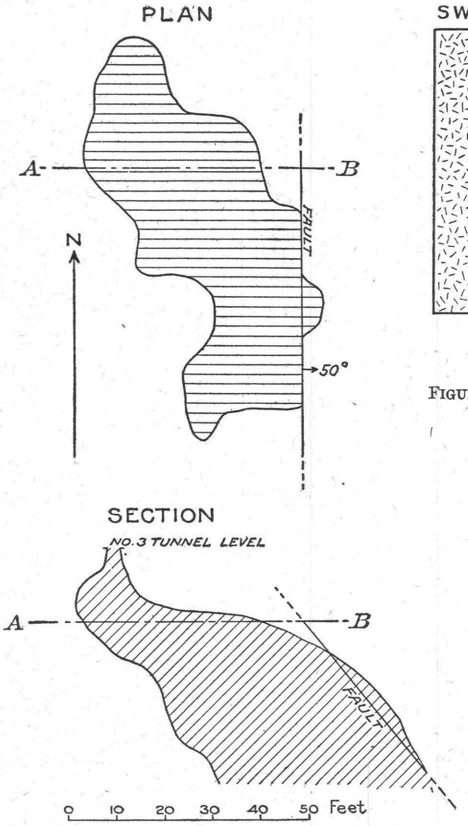


FIGURE 4.—Plan and section of stope near portal of level No. 3 of Empire mine. Fault plane can be traced through ore body but is accompanied by almost no gouge. It is believed to represent postmineral movement along a premineral fault.

stope. This stope is no longer accessible, but the description by these writers seems adequate.

These ["pipes" or "flues"] are surrounded, for perhaps a radius of 20 feet at the point exposed, by an intimate mixture of finely crystallized garnet and specularite, which carries pyrite and chalcopyrite and their products of oxidation, and fluorite in small but persistent quantity. Through this mass are vugs lined with crystalline garnet, and in several places angular fragments of unaltered quartz porphyry cemented in the mass, bearing testimony to the fumarolic process.

The pipes themselves are lined with incrustations of garnet and specularite. Crystalline purple fluorite is present and chalcopyrite occupies the spaces between the other minerals. Additional minerals of probably later origin are siderite incrusting the other minerals, gypsum, which occurs in a similar manner, and calcite, which has come in latest of all, filling the open spaces between the larger crystals and the cracks through the formation.

These pipes vary in size from those which are now closed, but which exhibit the original structure, to open channels from 8 to 10 inches across.[1]

The principal ore bodies in the Copper Bullion tunnel as now known are distributed irregularly along the margins of a great limestone

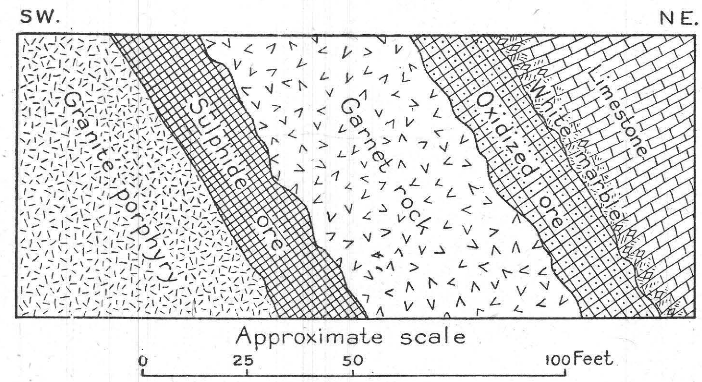


FIGURE 5.—Vertical section of ore body in northeast end of 400-foot level of Empire mine.

inclusion which crops out for 1,000 feet along a northeast course with an average width of about 200 feet. (See Pl. IX, *B*.) The Copper Bullion tunnel intersects this limestone slab at a depth of about 200 feet, and development has followed its margin for 100 feet above and below the tunnel level and 120 feet to the west and 160 feet to the east. Thus development has been entirely sufficient to afford a reliable conception of the broader geologic relations of the ore bodies here found. Three principal ore shoots are recognized, all of which are bordered on one side by the limestone or its local equivalent, white marble, and on the other by garnet rock or granite porphyry. The stopes here as elsewhere are exceedingly irregular on the limestone side; much more so than on the other, as illustrated by figures 6 and 7. The larger stopes are tabular in outline and parallel to the margins of the limestone slab, but locally chimneys of ore extend off into the limestone or follow up along sharp bends in the contact of the limestone and porphyry; locally they reach out along joints a short distance into the igneous rock. (See fig. 8.)

Most of the ore has been found on the south side of the inclusion, but to the west of the tunnel important bodies are opened on the

[1] Kemp, J. F., and Gunther, C. G., op. cit., pp. 292–293.

north side. These bodies have been followed through broad, flat stopes, which extend through

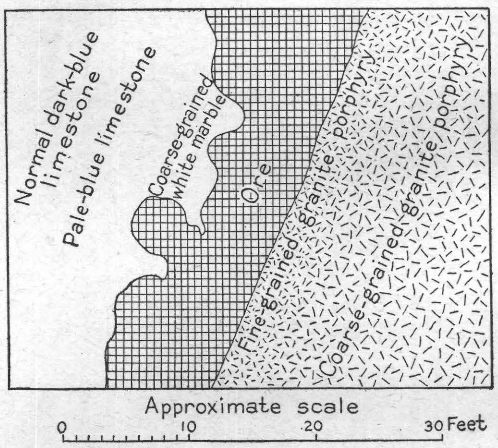


FIGURE 6.—Face of ore in open cut near portal of north tunnel, Empire mine.

the limestone slab and are connected with the other stope west of the tunnel. A similar body of ore, though much smaller, extends into the limestone from the south. A winze about 150 feet deep starts at the tunnel level and bears to the north-northeast, following a small pipe of ore on a sinuous course. Throughout its extent limestone and marble form the roof and quartz porphyry and garnet rock the floor. This ore body, though not proved to be particularly valuable, seems to represent a pipe which extends entirely through the limestone slab.

A body of ore wholly surrounded by the granite porphyry was found about halfway between the limestone inclusion and the portal. This ore is essentially similar to that adjacent to the limestone, and it is believed to have the same origin, the limestone here, however, having been entirely replaced.

The contact of the ore and the inclosing rock, wherever that is limestone or granite porphyry, is sharp in detail, although in its broader features, even in those of a hand specimen, it is exceedingly irregular. Where the inclosing rock is garnet there is in many places

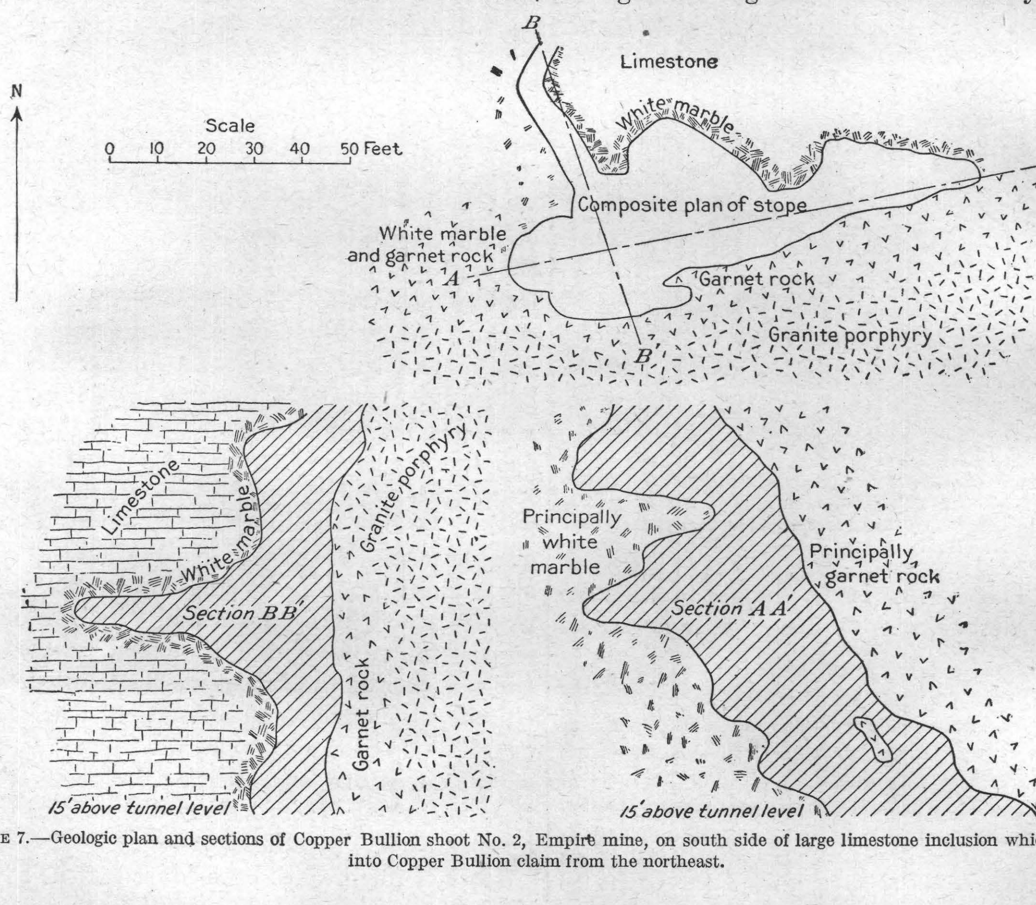
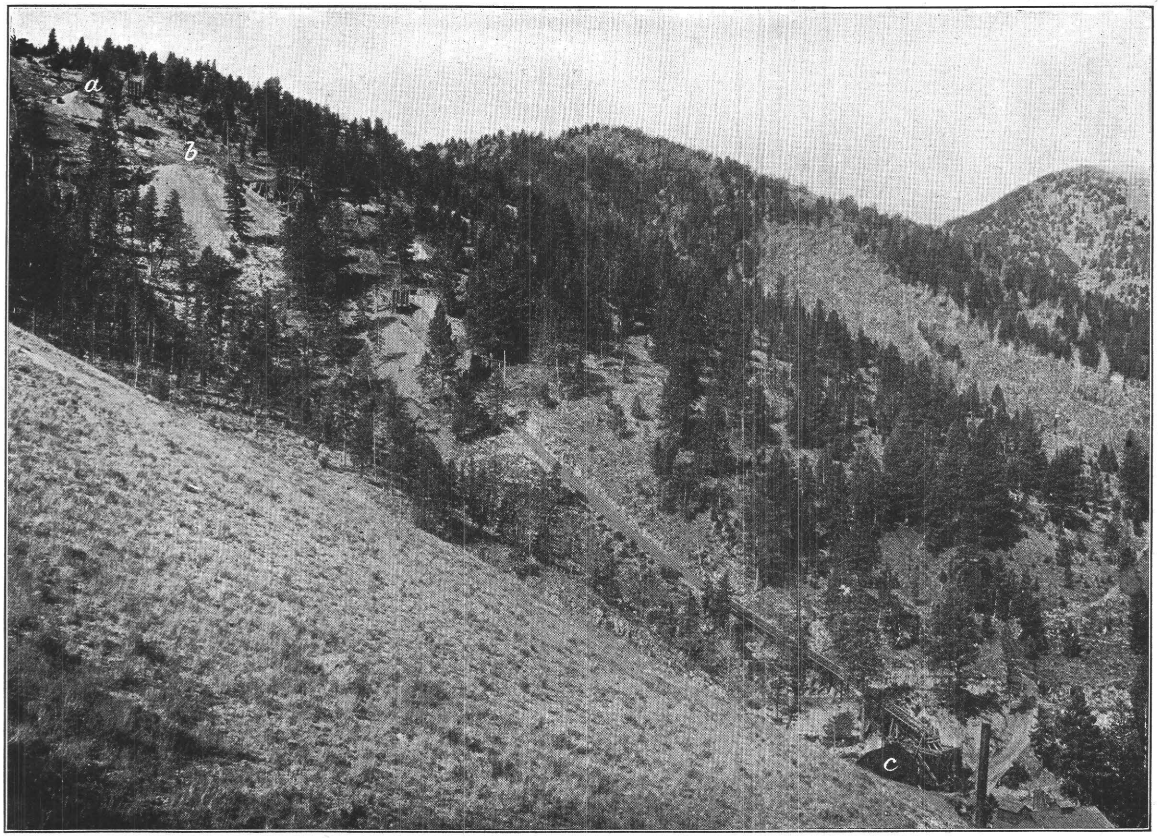
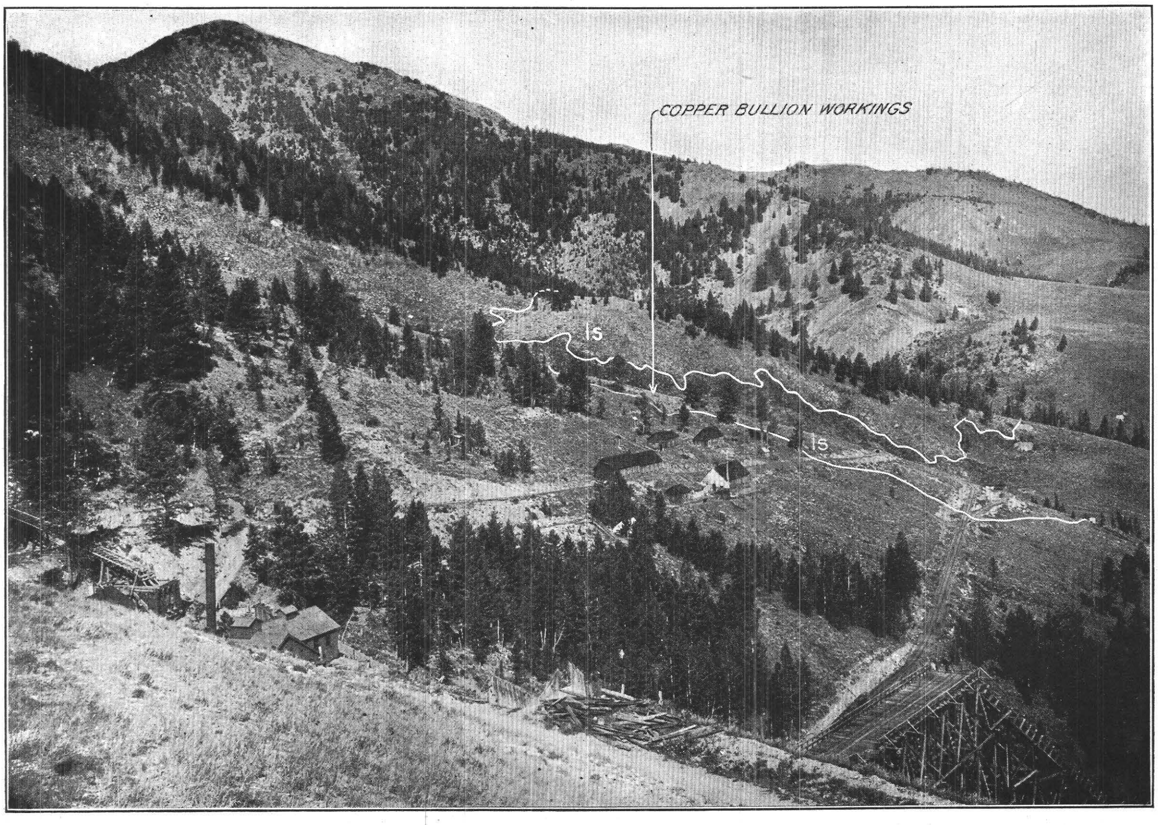


FIGURE 7.—Geologic plan and sections of Copper Bullion shoot No. 2, Empire mine, on south side of large limestone inclusion which extends into Copper Bullion claim from the northeast.



A. PRINCIPAL WORKINGS OF THE EMPIRE MINE, ALDER CREEK DISTRICT, IDAHO.
North tunnel level, *a;* 300-foot level, *b;* Alberta or 700-foot level, *c.*



B. CONTINUATION TO THE NORTH OF AREA SHOWN IN *A.*
The two areas marked "ls" are blocks of limestone engulfed in the granite porphyry.

a gradation between the ore and the barren formation inclosing it, but even here the transition is nearly complete within a few feet, in most places within a few inches. A striking feature and one found most valuable in locating shoots of ore is the presence of stringers which extend out locally 100 feet or more from the ore bodies. This connection of stringers with ore bodies is so general and so well recognized by those acquainted with the deposits that many profitable leases have been taken on exposures no wider than a knife blade. The stringers traverse both garnet rock and granite porphyry.

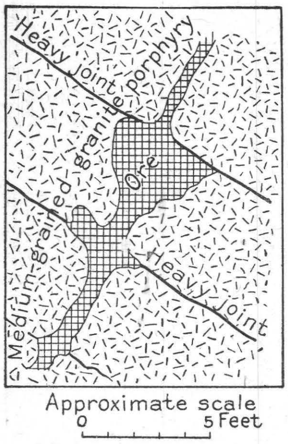


FIGURE 8.—Detail of relations in south face of Copper Bullion stope No. 2, Empire mine. Shows the replacement of granite porphyry after it had solidified.

ORES.

The ores of the Mackay deposits are valuable for the copper which they contain, though small amounts of gold and silver are associated with it. The primary ore comprises an intimate intergrowth of garnet and chalcopyrite, along with subordinate amounts of pyroxene, pyrite, and pyrrhotite, the abundance of chalcopyrite being such that the ore contains 5 to 6 per cent of copper to the ton. The sulphides are characteristically interstitial with respect to the silicate minerals, but in a few of the specimens chalcopyrite and pyrite occur well within garnet crystals. (See Pl. X, *B*.) The sulphide ore occurs only in the north Alberta shoot and in the Copper Bullion tunnel.

Far more abundant than the sulphide ore is the so-called chrysocolla ore, mined at more than 30 places on the Empire group of claims in 1912. This oxidized ore is characteristically a confused assemblage of variegated chrysocolla inclosing numerous blebs and wavy discontinuous bands of azurite and malachite and locally nodules of cuprite and ill-defined patches of copper pitch ore. Of the 56 mineral species which have been recognized in the deposits, 21 occur in secondary ores.

As is emphasized in the description of Alder Creek district (p. 99) it is noteworthy that secondary copper sulphides are exceedingly rare in the deposits and that no zone of sulphide enrichment separates the oxidized and primary ore.

MINERALOGY OF THE CONTACT DEPOSITS.

LIST OF MINERALS.

Fifty-seven mineral species have been recognized in the collection from the Alder Creek district, and most of them are probably also present in the Copper Basin district. One of these, custerite, is a new species; 14 are nonmetallic contact metamorphic minerals; 10 are primary metallic minerals; 21 are secondary metallic minerals; 3 predominate in the sedimentary rocks, and 3 occur principally as the products of normal rock weathering. In many particulars this classification is arbitrary, as several of the minerals fall in more than one group. It serves to point out, however, the marked increase during contact metamorphism in the number of mineral species in the deposits and the further breaking up of these minerals, particularly the metallic ones, into a still greater number of species as a result of oxidation, hydration, and related processes in the zone of weathering. In the primary ore copper has been recognized definitely in but one form; in the oxidized ore it is an important constituent of 11 mineral species.

The garnets grossularite and andradite are about equally abundant and constitute perhaps 80 per cent of the secondary lime silicate rock. Magnetite and chalcopyrite in about equal amounts greatly exceed pyrite and pyrrhotite as primary metallic minerals. In the oxidized ore chrysocolla, including under that name large amounts of amorphous material composed of copper, iron, and silica, probably comprises more than 80 per cent of the mass.

In the following pages the ore and gangue minerals are listed in alphabetic order, with notes on habit and occurrence:

Actinolite.—The contact mineral actinolite ($CaO.3(MgO.FeO).4SiO_2$), so abundant in many similar deposits, occurs but sparingly in the Mackay silicate rocks, its usual occurrence being as finely divided crystals in white marble.

Kemp and Gunther,[1] however, describe a vein of it "about 2 inches thick of fibrous or acicular crystals in apparently unchanged blue limestone."

Andradite.—In all types of garnet in the deposits the andradite molecule ($3CaO.Fe_2O_3.3SiO_2$) is an important constituent. In the massive garnet it comprises about 50 per cent of the entire mass, and in the dark amber-colored garnet, which formed subsequently, it is even more abundant. From the color of the garnet it seems possible as a rule to tell whether it is andradite or grossularite. Both of these varieties, however, as determined by index solutions, may be of so nearly the same shade of amber color that no difference between them can be detected.

Apatite.—Apatite ($Ca_4(CaF)(PO_4)_3$) is a persistent accessory mineral in the granite porphyry and occurs locally in small amounts in the lime silicate rock.

Augite.—The complex magnesium-aluminum silicate, augite, is an abundant constituent of the pyroxene rock. As a rule it seems to have developed larger grains than the diopside and hedenbergite. Its relative amount appears to differ greatly in the different sections, though its optical similarity to diopside makes estimates rather unreliable. The observation, however, is supported by the two analyses, one of which represents 10 per cent of augite and the other 27 per cent.

Azurite.—The basic carbonate of copper, azurite ($Cu_3.(OH)_2(CO_3)_2$), accompanies malachite in the oxidized ores. It is not an abundant mineral in the deposits, though very generally present in the different stopes. Locally it is well crystallized in tabular monoclinic forms.

Biotite.—The form of mica known as biotite is an essential constituent of the igneous rocks of the district. During the endomorphism of granite porphyry it is changed to diopside next after hornblende.

Bornite.—The copper-iron sulphide, bornite (Cu_3FeS_3), is a rare secondary mineral observed only in the partly oxidized ores. It forms narrow veinlets along joints in chalcopyrite, from which it seems to have developed.

Brochantite.—The emerald-green hydrous copper sulphate, brochantite ($Cu_4(OH)_6SO_4$), is almost as abundant in the Mackay deposits as is malachite, with which it is commonly intergrown. In a few specimens it is intergrown with azurite, affording a beautiful blending of blue and green colors. (See Pl. XVI, *A*, p. 68.) Rarely it is crystallized in short thick orthorhombic prisms which are vertically strained. In places in the 300-foot Empire tunnel it forms the central portion of narrow veins of azurite in limestone. It is likely to be confused with malachite but may be distinguished from it by the sulphuric-acid test and lack of effervescence in hydrochloric acid.

Calamine.—Calamine ($Zn_2(OH)_2SiO_3$) was observed only in the ore of the Champion group, and here it is exceedingly rare. The single specimen collected shows a group of acicular crystals set on a drusy surface of smithsonite.

Calcite.—Calcium carbonate in the form of calcite is abundant in the deposits, occurring alike in primary and oxidized ore. In the primary ore it is commonly an interstitial filling between garnet grains; in the oxidized ore it occurs as veinlets and in vugs. It has not been observed in garnet rock that is clearly of porphyry derivation.

Chalcanthite.—The blue vitriol, chalcanthite ($CuSO_4+5H_2O$), occurs sparingly in the Copper Bullion ores as thin coatings composed of distinctly fibrous crystals. It was not observed elsewhere.

Chalcedony.—Silica in the form of chalcedony is probably represented by some of the cherty lenses and nodules in the lower limestone beds of the district. It also occurs in vesicles in the eruptive rocks. It was not recognized in the ores.

Chalcocite.—Chalcocite (Cu_2S) is rare in the deposits. It has been detected in only two hand specimens. In one of these specimens a thin film of copper glance follows a fracture plane; in the other the mineral occurs as minute specks embedded in chrysocolla in the central part of a nodular mass of predominantly carbonate minerals.

Chalcopyrite.—By far the most abundant primary mineral of copper is chalcopyrite ($CuFeS_2$). It occurs as an interstitial filling in garnet rock, and in a few specimens grains of it are concentrically distributed in garnet crystals. Magnetite and chalcopyrite seldom occur in the same hand specimen, and even in an ore shoot where one is abundant the other is scarce.

[1] Kemp, J. F., and Gunther, G. C., op. cit., p. 285.

It is intimately associated with pyrite and in many specimens completely surrounds garnet crystals.

Chlorite.—The secondary silicate mineral, chlorite, occurs only as the product of normal weathering of biotite and hornblende in the igneous rocks and of pyroxene in the metamorphic silicate rocks.

Chrysocolla.—By far the most abundant mineral of the oxidized ores is chrysocolla ($CuSiO_3+2H_2O$). It is characteristically brown in color and has a vitreous to dull luster and conchoidal fracture. Locally, where not ferruginous, it is bluish green and has a vitreous luster. This variety, as seen in index solutions, is about 90 per cent crystalline; the other variety is mostly amorphous and is characterized by the concentric banding described on page 67. Where the green and brown varieties are in juxtaposition they are separated by a sharp boundary, but the green variety passes through imperceptible gradations into almost black copper pitch ore. The brown variety also grades into reddish-yellow ferruginous material, little of which, however, fails to react for copper. Thus the characteristic silicate ore shades from reddish-yellow through brown to brownish-black. The different colors are heterogeneously arranged, giving both a hand specimen and a breast of ore a variegated, blotchy appearance.

Analyses of the bluish-green crystalline material and the reddish-yellow variety appear below.

Partial analyses of chrysocolla ore.

[R. C. Wells, analyst.]

	1 Principally crystallized.	2 Principally amorphous.	Ratios.
SiO_2	39.3	29.6	0.65
CuO	32.0	19.4	.40
H_2O	18.7	17.9	1.05
Al_2O_3 (etc.)	2.4	5.6	.02
Fe_2O_3		24.0	
FeO		.2	
CaO	1.7	1.9	.03
ZnO	3.6		.05
MgO	Trace.	.5	
	97.7	99.1	

Approximate amounts of minerals (analysis 1):

Chrysocolla: $CuO, SiO_2, 2H_2O$	87.3
Kaolinite: $2SiO_2, Al_2O_3, 2H_2O$	4.5
Opal: $SiO_2\ n\ H_2O$ (3.85 per cent H_2O)	8.2

As the first analysis is of material which in the main is homogeneous and well crystallized an effort was made to estimate microscopically the quantity of impurities to be deducted in determining the molecular ratios of the chrysocolla. It is clear from the microscopic studies that both kaolinite and opal are present. The kaolinite occurs as films along cracks, and on crushing the material much of it separates as minute shreds and leafy aggregates. Its quantity could not be estimated. The opal, however, breaks as does the chrysocolla, and a fairly satisfactory estimate of its quantity may be made. Ten portions of the powder analyzed were examined in index solution, and all specimens of amorphous material with lower index than 1.45 were regarded as opal. Of the 10 portions, in each of which 100 grains were examined, it was found that an average of 9 out of 100 were opal, the range being from 5 to 14, though most of the determinations approximated the average. In some of the grains both amorphous and crystalline material occurs, thus adding to the inaccuracy of the estimate. Furthermore, most of the opal is bluish, indicating that it contains some copper. From the analysis the proportion of minerals present was calculated. The quantity of alumina found was assumed to be combined in kaolinite, and the quantities of copper, zinc, and calcium oxides determined, the amount of silica and water to be assigned to chrysocolla in keeping with its commonly accepted formula. The remaining analytic constituents, silica and water, were computed as opal. The opal thus computed contains 3.85 per cent of water, a reasonable amount, and the total opal is 8.2 per cent of the mass, which accords well with the 9 per cent estimated by microscopic examination of the powdered material.

An interesting feature of the analytical work is that in three determinations of water the widely different values of 21.2, 16.3, and 18.7 were obtained. Only the last, however, was made on the portion of the powder analyzed.

The crystallized chrysocolla is particularly interesting because many of its optical properties may be definitely determined. It occurs as acicular crystals of both parallel and radial disposition and as irregular grains and mammillary crusts. The mineral is uniaxial and optically positive and has positive elongation and high birefringence. The indices of refraction are ω 1.46 and ε 1.54+, a small variation in the values from different grains making it unwise to attempt to carry the value to the third decimal place. Thick grains show a slight pleochroism in colorless (ω) and pale bluish-green (ε) tints. The mineral belongs to the hexagonal or tetragonal system of crystallization. Its physical properties are: Hardness, about 3; density, 2.4±; luster, vitreous; color, pale bluish green; streak, white; and tenacity, brittle.

The second partial analysis is of reddish-yellow material which from its appearance would be thought to contain little if any copper. It is amorphous in large part, and in it microscopic concentric structure is abundantly developed. The alternating layers present different shades of red and yellow. In a few of the grains chrysocolla was observed in isolated crystals, small aggregates, and narrow layers of closely packed fibers, but this does not comprise more than 4 per cent of the total mass.

Copper.—Thin films of metallic copper were observed along fractures in a specimen from the 300-foot Empire level, and minute specks of it occur in some of the nodules of cuprite. It is extremely rare in the deposits.

Copper pitch ore.—According to Lindgren's definition [1] the term copper-pitch ore designates "a dark-brown to black substance, sometimes dull but generally with glassy to resinous luster; hardness, about 4; streak, dark brown." It reacts strongly for manganese. Its characteristic occurrence near Mackay is in irregular areas which on their border blend with chrysocolla. The substance seems to grade into chrysocolla in many specimens, but its contact with other ore minerals is sharp.

Covellite.—Copper sulphide (CuS) of indigo-blue color was observed as films on other sulphides in several parts of the Empire mine. A specimen from the Hearst tunnel (a small unmapped opening west of the 300-foot tunnel dump) shows covellite developed along the cleavage planes of chalcopyrite and comprising about 60 per cent of the mass. (See Pl. XVI, *D*.)

Cuprite.—Several specimens of ore from the 300-foot level of the Alberta mine contain nodular bunches of cuprite (Cu_2O) embedded in chrysocolla. They are an inch or less across and are invariably surrounded by a layer of tenorite about one-eighth of an inch thick.

Custerite.—A hydrous fluosilicate of calcium ($Ca_4Si_2H_2F_2O_8$) was first described from these deposits [2] under the name custerite. It occurs as finely granular masses closely associated with magnetite in a group of prospects a short distance beyond the crest of the high ridge northwest of the Copper Bullion tunnel. It occurs on the inner edge of a fringe of garnet-diopside rock which surrounds a large limestone inclusion. Its physical properties are: Hardness, 5; density, 2.91; luster, greasy to vitreous; streak, white; color, pale greenish gray; brittle; translucent. The mineral has three cleavage directions and the polysynthetic twinning is parallel to 001. It is optically positive; refringence, high; birefringence, moderate to weak; maximum extinction on the twinning lamellæ, 6° to 7°. Results obtained by analysis of the mineral are shown in the following table:

Analyses and ratios of custerite.

[W. T. Schaller, analyst.]

	1	2	Average.	Ratios.
SiO_2	32.13	32.20	32.17	0.536
CaO	55.11	......	55.11	.984
H_2O	5.53	5.06	5.30	.294
F	8.12	......	8.12	.427
MgO	1.19	1.19	1.19	.030
Magnetite	.85	1.14	1.00	......
			102.89	
Excess of O due to F	......	......	3.42	
			99.47	

Diopside.—Diopside ($CaO.MgO.2SiO_2$) is an abundant mineral constituent of the deposits. It predominates in the pyroxene rock, and during the endomorphism of the granite porphyry it was formed after hornblende and biotite as the earliest product of metamorphism. It is finely divided in much of the garnet rock but along with hedenbergite and augite comprises bunches of pyroxene rock free from garnet. Such rock is dense, greenish, of aphanitic texture and has resinous to vitreous luster.

Dolomite.—Magnesium carbonate, as suggested by the analyses and confirmed by the

[1] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, p. 114, 1905.

[2] Umpleby, J. B., Schaller, W. T., and Larsen, E. S., Custerite, a new contact-metamorphic mineral: Am. Jour. Sci., 4th ser., vol. 36, pp. 385-394, 1913.

thin sections, is present in most of the limestones, forming the mineral dolomite. It was not observed, however, in the interstitial carbonate filling in the garnet rock. Apparently the magnesium was entirely used up during the earlier stages of metamorphism, when diopside was being formed.

Feldspars.—Feldspars ranging in composition from orthoclase to andesine occur in the granite porphyry. More calcic varieties have been recognized in the garnet rock but are rare.

Fluorite.—Calcium fluoride, fluorite, is widely distributed in the ore deposits and in the lime silicate rock near them. Because of its general meagerness in contact deposits its presence here in considerable amounts is particularly noteworthy. Chunks weighing several pounds are present in the dump from the "big quarry" of the Empire mine. Elsewhere it occurs as isolated grains and veinlets.

Galena.—Only small amounts of galena (PbS) have been found in the district. On the Kennedy group, near mineral monument No. 1, it occurs in a siderite gangue as veins in granite; in tunnel No. 2 of the Champion group as irregular bunches in the crushed footwall of a fault in limestone; and on the Easlie group along the contact of granite porphyry and an engulfed block of limestone. Two or three cars of mixed ore, principally galena, have been shipped from the district.

Garnet.—Garnet is by far the most abundant mineral in the deposits. Grossularite ($3CaO.Al_2O_3.3SiO_2$) and andradite ($3CaO.Fe_2O_3.3SiO_2$) have been recognized in numerous specimens. Other varieties have not been distinguished microscopically, but a computation of the analyses shows also the presence of the almandite ($3FeO.Al_2O_3.3SiO_2$), pyrope ($3MgO.Al_2O_3.3SiO_2$), and spessartite ($3MnO.Al_2O_33SiO_2$) molecules. (See table, p. 63.) The garnet occurs as euhedral crystals where embedded in calcite or along joints; elsewhere the individuals are anhedral, owing to mutual interference. It locally includes cores of mixed magnetite, calcite, and quartz and concentrically distributed grains of chalcopyrite. Much of it shows zones of anomalous birefringence in thin section under crossed nicols. The garnet ranges in index of refraction from 1.82 (analysis No. 7) to $1.84 \pm .003$ (analysis No. 8).

Gold.—Free gold has not been detected in the ore specimens, but it is quite probably present as minute particles, at least in the oxidized portions of the deposits, as suggested by the assay returns.

Grossularite.—In this district garnet occurs characteristically as a dense aphanitic rock of greasy to vitreous luster. In many places along the workings of the Alberta level this type of rock is continuous for scores of feet. In many of the thin sections nothing but garnet and a chance grain or patch of residual calcite appear. Next to the calcite the garnet crystals are euhedral; away from it they mutually interfere until crystal outlines are lost. Analyses of this massive garnet rock show the presence of 35 to 45 per cent of the lime garnet grossularite ($3CaO.Al_2O_3.3SiO_2$) or its molecule.

Gypsum.—The common sulphate of calcium, gypsum ($CaSO_4$), occurs sparingly as veinlets in the oxidized ore and wall rock adjacent to it. Few of the veinlets exceed half an inch in width and many are less than a millimeter across. The mineral also occurs as irregular grains sparsely scattered in the oxidized ore.

Hedenbergite.—The pyroxene known as hedenbergite, a calcium-iron silicate, appears in only a few of the thin sections as a distinct mineral, but in the computation of the analyses its molecule is shown to be present in amounts ranging from 9 to 23 per cent. Its presence, like that of andradite, is of particular interest because of the large amount of iron which it contains.

Hematite.—The ferric oxide of iron, hematite (Fe_2O_3), occurs throughout the oxidized ore and near the surface in all areas of lime silicate rock. It is much more abundant than limonite.

Hornblende.—Common hornblende ($Mg_3Ca_2FeSi_6O_{18}$) is one of the essential constituents of the granite porphyry. It is the first mineral attacked during endomorphism, diopside being developed after it.

Kaolinite.—In many places in the oxidized ores kaolinite occurs along fractures and in cavities. It seems to have formed only during the normal weathering of the aluminous garnet and the igneous rocks.

Limonite.—The oxide of iron known as limonite ($Fe_2O_3.3H_2O$) is abundant as a yellowish-red stain in areas of magnetite, specularite garnet, and diopside.

Magnetite.—The magnetic oxide of iron, magnetite (Fe_3O_4), is abundantly developed in the vicinity of the Iron and Quarry tunnels and locally throughout the deposits. It is characteristically fine grained and associated with specularite and an equal or greater amount of garnet. It is not abundant in association with chalcopyrite. On the ridge northwest of Copper Bullion tunnel it occurs as veinlets of coarse crystals cutting the garnet rock. Here as elsewhere, however, the garnet contains cores of magnetite. Common assays of the magnetite rock contain 50 per cent iron and 1 per cent copper, and 0.002 ounce gold and 0.57 ounce silver to the ton.

Malachite.—The bright-green basic copper carbonate, malachite, is a persistent though subordinate mineral of the oxidized ores. It occurs in intimate association with chrysocolla, azurite, brochantite, and the other secondary copper minerals. It is likely to be confused only with brochantite, which, however, is a duller green in most places and does not effervesce with acid. The malachite commonly occurs as bunches of irregular shape in the silicate ore and as crusts alternating with azurite in tabular, lenticular, and nodular masses. (See Pl. XV, *A*.)

Opal.—Silica in the form of opal is common as microscopic grains in much of the "chrysocolla" ore. It is readily identified in index solutions by its isotropism and low refringence.

Pyrite.—Pyrite (FeS_2), next to magnetite and chalcopyrite, is the most abundant primary metallic mineral. It occurs both as coherent grains and intricately fractured grains with chalcopyrite along the fractures. The chalcopyrite in many such specimens represents more than half the total area. In many places it is interstitial with respect to garnet crystals.

Pyrolusite.—Manganese dioxide, pyrolusite, occurs as dendrites on fracture surfaces in the limestone and as black sooty material mixed with iron oxide in the oxidized ore.

Pyroxene.—Pyroxene rock next after garnet rock is the most abundant product of metamorphism in the vicinity of the Empire mine. It is characteristically a dense greenish-gray rock of aphanitic texture and resinous to vitreous luster. As seen in thin section under the microscope it is made up of diopside, augite, and hedenbergite, named in order of abundance. In some of the sections is a little plagioclase feldspar ($Ab_{65}An_{35}$), and chance grains of titanite, apatite, and fluorite.

Pyrrhotite.—Magnetic iron sulphide, pyrrhotite (Fe_nS_{n+1}), may be extracted in small amounts from crushed samples of most of the sulphide ore. It is present as grains so minute that it is readily detected only with the aid of a magnet.

Quartz.—Quartz is meagerly developed in the deposits. It occurs in small amounts in the limestone and ores. In a few sections grains of it are embedded in the central part of garnet crystals.

Scapolite.—The complex calcium-sodium-aluminum silicate, scapolite, is reported by Kemp and Gunther[1] as occurring in one of their slides. It was not detected in any of the sections studied by the writer.

Sericite.—Fibrous-felted muscovite, or sericite ($H_2KAl_3(SiO_4)_3$), so abundant in the wall rock of many deposits, is meagerly developed in the Mackay deposits. It has been detected in specimens of the granite porphyry only from the vicinity of the Iron tunnel. In the trachyte porphyry dikes it is abundantly developed after orthoclase. Here, however, it is believed to be the product of normal weathering rather than of hydrothermal metamorphism.

Serpentine.—The hydrous magnesium silicate, serpentine ($H_4(Mg,Fe)_3Si_2O_9$), is a meager constituent of the deposits. It occurs as an alteration product after hornblende and diopside. In the raise from the North Alberta stope to level No. 300 a band of serpentine with intermixed quartz and malachite follows the fault plane. The layer is about 2 inches wide and shows evidence of much shearing.

Siderite.—Iron carbonate, siderite ($FeCO_3$), is said to be the gangue mineral in the lead-bearing vein opened from the Darlington shaft on the Empire group.

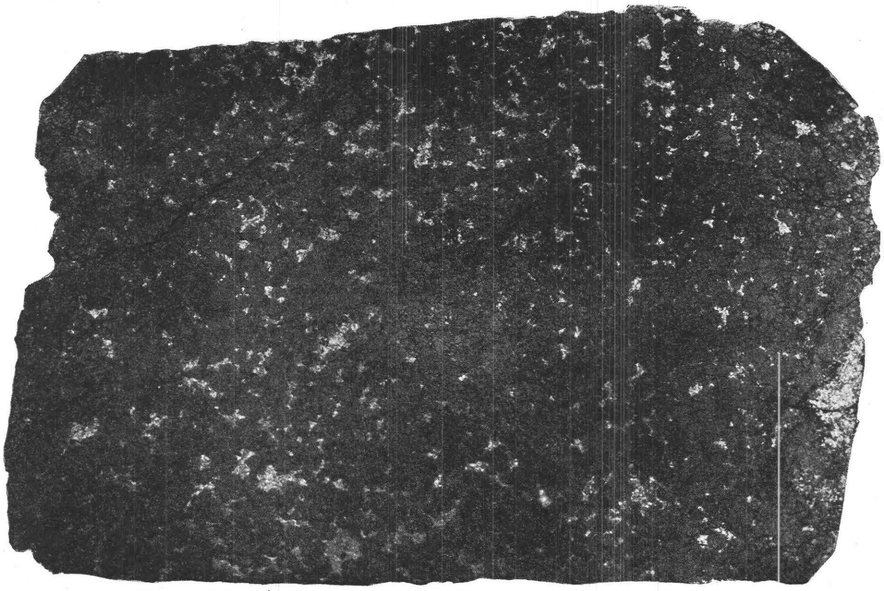
Smithsonite.—Zinc carbonate, smithsonite ($ZnCO_3$), was observed only in the Champion mine, where it occurs as a rare constituent of the oxidized lead ore.

Specularite.—Black nonmagnetic iron oxide, specularite (Fe_2O_3), is abundant in much of the magnetite rock, where it occurs as druses in cavities and as finely divided grains.

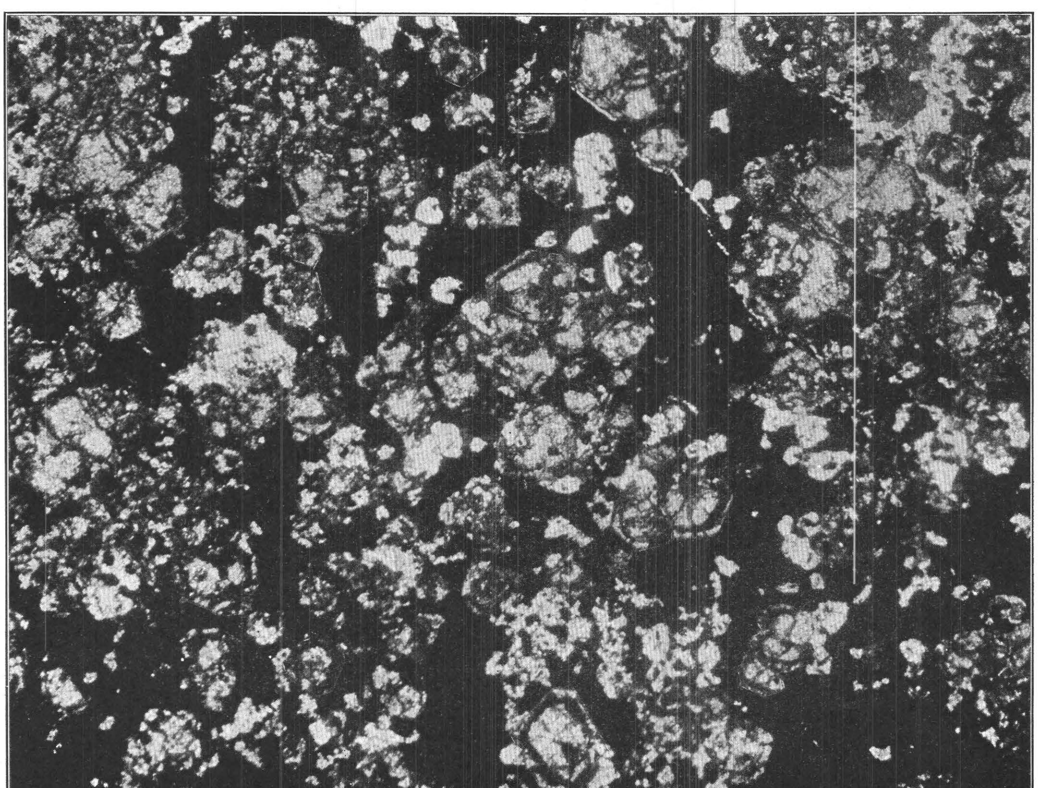
Sphalerite.—Sphalerite (ZnS) is a rare mineral in the district. Scattered grains of it occur in the lead prospects.

Tenorite.—Bright black layers which envelop nodular masses of cuprite from the 300-foot

[1] Kemp, J. F., and Gunther, G. C., op. cit., p. 288.

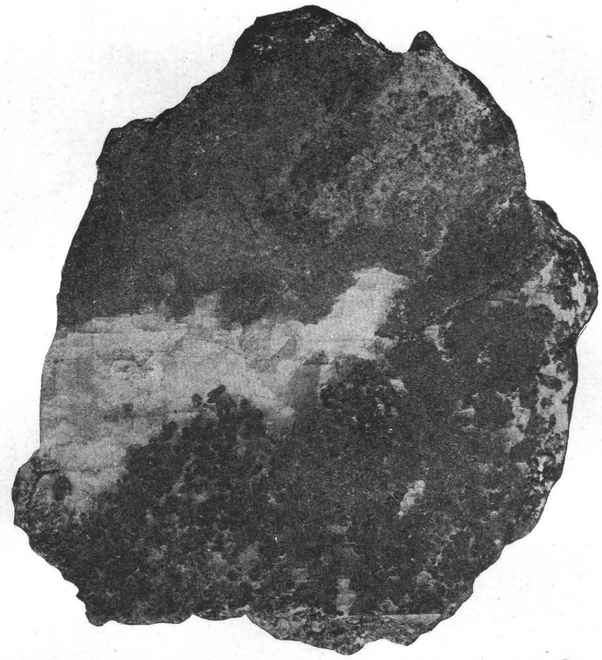


A. TYPICAL PRIMARY ORE, EMPIRE MINE, ALDER CREEK DISTRICT, IDAHO.
Chalcopyrite (white) and garnet. Natural size.

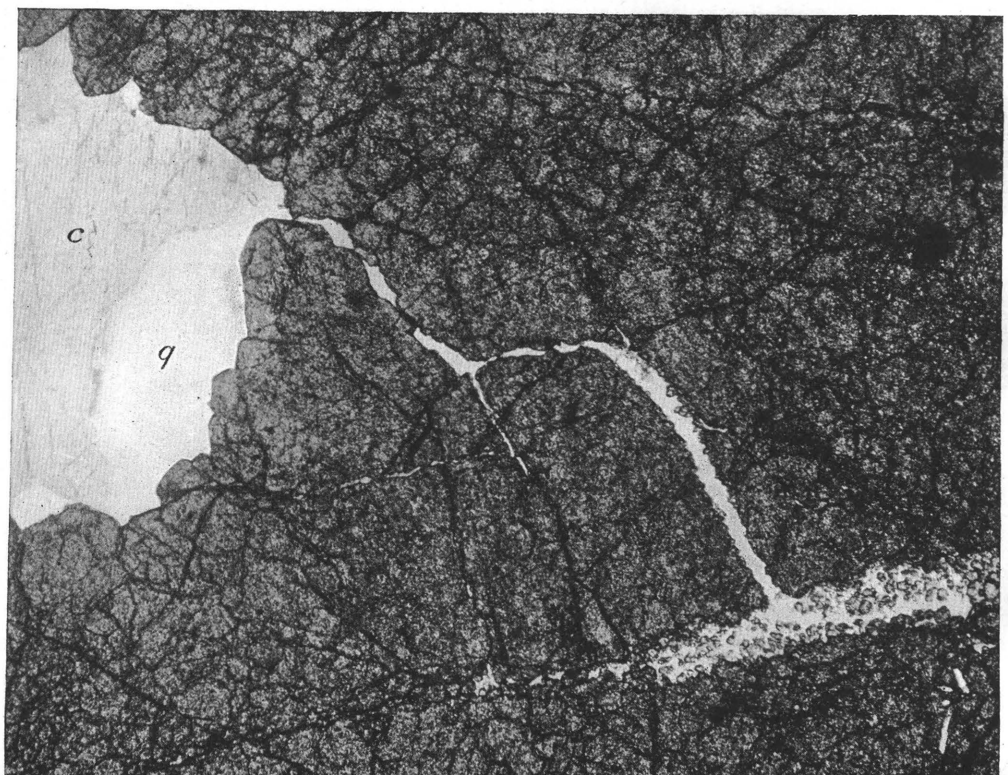


B. GARNET CRYSTALS (WHITE) CONTAINING CHALCOPYRITE.
Section from specimen shown in *A.* Parallel light. $\times$ 50.

A



B



C

TYPICAL SPECIMENS FROM THE EMPIRE CONTACT DEPOSITS, ALDER CREEK DISTRICT, IDAHO.

A. Chalcopyrite (light) after residual calcite in garnet-calcite rock like the rock shown in *B*. Natural size.
B. Garnet and residual calcite. Natural size.
C. Garnet and residual calcite (*c*) traversed and in part replaced by quartz (*q*). Parallel light. × 30.

Empire level are probably the cupric oxide tenorite (CuO). The material has chrysocolla and malachite intermixed with it, and the amount is so small that careful chemical examination was not attempted.

Tetrahedrite.—Gray copper, tetrahedrite (Cu_8-Sb_2S_7), has been observed as small patches in some of the partly oxidized ore from the Copper Bullion tunnel. It is exceedingly rare in the deposits.

Tremolite.—The calcium-magnesium silicate, tremolite ($CaO.3MgO.4SiO_2$), occurs sparingly in the marmarized limestone and is rare in the diopside rock.

Vesuvianite.—The complex calcium-aluminum silicate, vesuvianite, occurs in No. 4 crosscut from the Alberta tunnel as bunches of acicular radiating crystals which replace dull-gray manganese-stained limestone. The largest bunches are one-half inch in diameter. It was not observed elsewhere in the deposits.

Wollastonite.—Wollastonite ($CaO.SiO_2$) was observed as scattered crystals in a great many of the thin sections of marble and garnet rock. Locally it occurs as a layer a foot or less in width between the granite porphyry and unaltered blue-black limestone. On the side of the wollastonite away from the igneous rock is a persistent narrow layer of pale-blue marble, bordered by a silicified zone of blue limestone, which grades outward through a foot or 18 inches into the unaltered rock.

PARAGENESIS OF THE MINERALS.

No rigid sequence in mineral formation has been recognized in the one hundred or more specimens collected from the contact deposits. In places veinlets of magnetite cut across garnet rock, but elsewhere grains of it are clustered in the centers of fresh garnet crystals. Chalcopyrite in many places bears the same relation to garnet and diopside crystals as does interstitial calcite (Pl. XI and fig. 11, p. 63). The calcite is certainly residual, and hence the relation may suggest that chalcopyrite has replaced calcite after garnets had ceased to form. Perhaps in the same specimen, however, chalcopyrite occurs zonally distributed well within crystals of garnet (Pl. X). In the Copper Bullion shoots the persistent occurrence of the ore on the limestone side of garnet masses also suggests that the ore minerals are later than the lime silicates. In the metamorphism of the granite porphyry diopside was the first mineral to form (see Pl. XIV, *C*, p. 60), but within limestone areas garnet is euhedral against it. In the granite porphyry the fact that the diopside replaces hornblende, a mineral of similar molecular structure, may account for its earlier development. Fluorite is common both as veinlets in the lime silicate rock and as intergrowths with garnet crystals. It has been detected also in two slides of the granite porphyry.

In general it is true that magnetite and the sulphides are interstitial with respect to the lime silicate minerals and were formed later. Fluorite also is in most places a later mineral.

METAMORPHIC PHENOMENA.

PROCESSES.

The metamorphic phenomena at Mackay include the transformation of limestone into marble and garnet rock and the transformation of the granite porphyry itself into garnet rock. The deposits therefore present both exomorphism and endomorphism. The endomorphism, however, is vastly less extensive than the exomorphism and apparently occurs only adjacent to garnet rock derived from limestone. The deposits are believed to record both metamorphism at the time of intrusion and metasomatism at a subsequent time.

Hydrothermal metamorphism has not been a noteworthy process in the deposits, though a little sericite has been recognized in several of the thin sections.

The products of oxidation and hydration in the oxidized zone are particularly interesting because of the preponderance of amorphous constituents, the radial disposition of crystals, and the meager transfer of material which they seem to imply.

EXOMORPHISM.

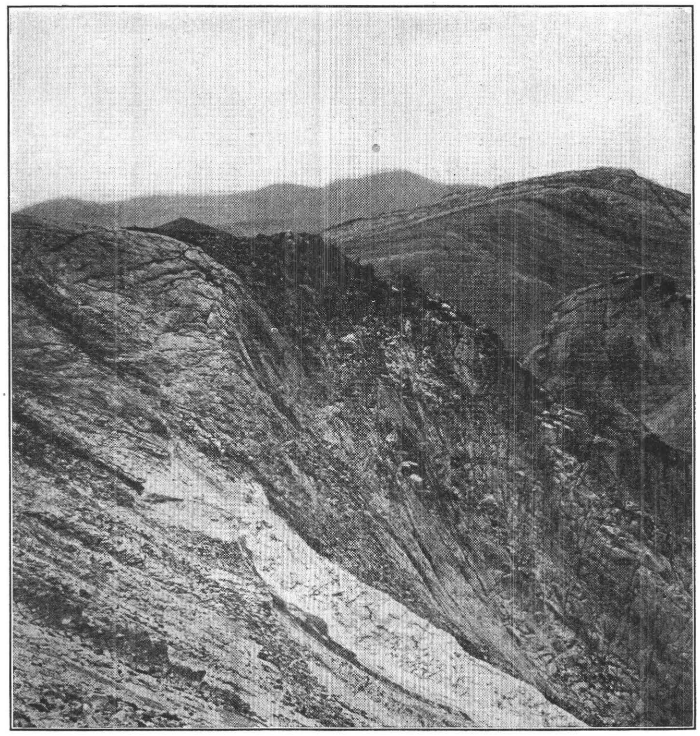
Marmarization of the limestone.—Marble is developed in important amounts at only one place along the several miles of the contact of the limestone and the granite porphyry; in most places it is scarcely discernible. Its best development is on White Knob, a mountain about 3 miles west of the Empire mine, so named because it stands out as a great white monument on a field of blue, gray, and green. (See Pl. XII.) The marble mass is about a square mile in area and rests on granite porphyry, which is exposed in four great cirques that head against it. On the northwest side it connects with the main limestone area, indicating that the marble represents a part of the roof of the batholith and not an embayed block. The contact of the marble and the granite porphyry, which is exposed on three sides of the knob, is about 9,500 feet above the sea and 1,000 feet lower than the summit, thus indicating that the marble mass is about 1,000 feet thick. The rock, which retains a distinct bedding structure from the original limestone, strikes north and dips 80°–85° E. It is possible, therefore, to follow a given bed continuously for about 1,000 feet away from the igneous contact. In this distance no constant changes in the intensity or character of the metamorphism were recognized. In places the marble is coarse textured, elsewhere fine. Some beds are bleached slightly; some still retain the blue of the original limestone; but most of them are milky white. None of these differences, however, appears to bear any definite relation to the proximity of the igneous mass. Thin sections of the marble reveal minute and rather uniformly distributed crystals of diopside, and here and there one of wollastonite and tremolite in a matrix of calcite, which is clear and apparently contains no foreign matter. (See Pl. XIII.) The silicate minerals seem to be no more abundant next to the igneous contact than elsewhere in the marble mass, except in the form of veins to be described later.

The relations described above are interpreted to mean that during the marmarization physicochemical conditions were essentially uniform throughout this great roof segment, which as now exposed is about 1 square mile in area and 1,000 feet in thickness. The two specimens of granite porphyry adjacent, which were examined microscopically, show no evidence of hydrothermal metamorphism. Perhaps more noteworthy than this, however, is the absence of similar marmarization along vertical portions of the contact of the limestone and the granite porphyry.

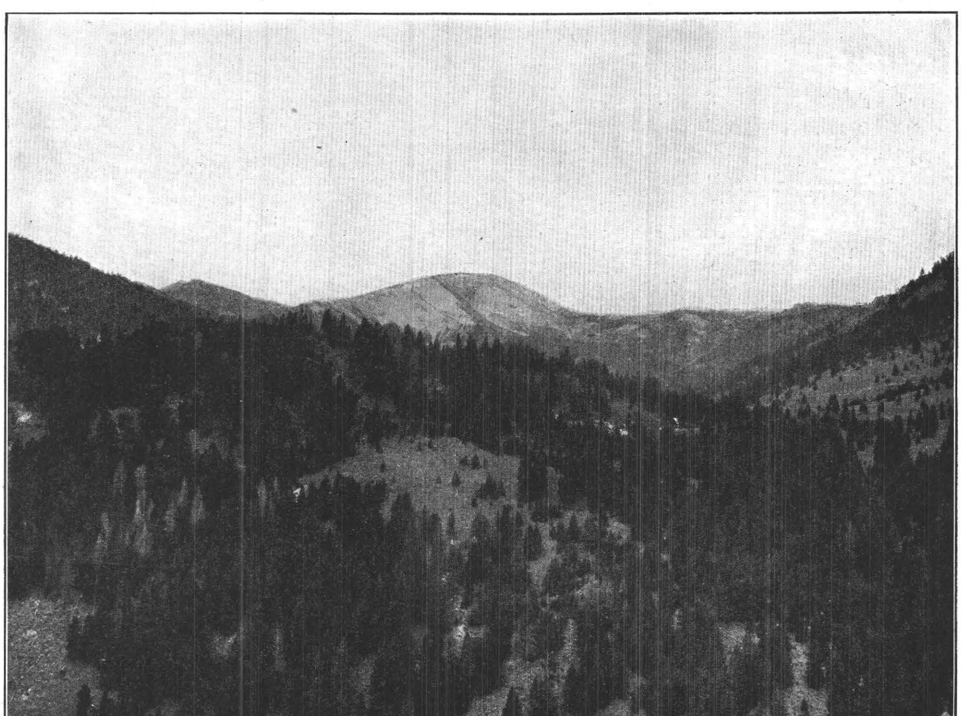
The occurrence of marble about the several blocks of engulfed limestone is more persistent than along the periphery of the batholith, but here also it has a considerable range in width. Four separate blocks of engulfed limestone are portrayed on the special map (Pl. VIII). In the mapping the marble was included with the limestone and the garnet rock with the granite porphyry. Marble, however, constitutes only a minor part of most of the areas shown as limestone and in only one place, the large inclusion northwest of the Copper Bullion tunnel, is garnet rock extensively developed. Of the four inclusions represented near the north edge of the map the easternmost is composed of chert which, up to the very contact, is apparently unmetamorphosed. The other three areas contain limestone bordered by a zone of marble a few inches or perhaps 2 feet wide. The large limestone inclusion northwest of the Copper Bullion tunnel is changed to marble for about 100 feet on the southwest side and to garnet rock containing magnetite for 100 feet beyond. On the northeast side of the same engulfed block, however, the marble aureole is only 2 or 3 feet wide. The large inclusion of limestone which extends into the Copper Bullion claim shows only a little marmarization at the surface, but at a depth of about 200 feet, where its north end has been extensively explored, the marble border is about 3 feet in average width. In places here the transformation is represented by a zone not more than 1 or 2 inches wide; elsewhere, as in stope No. 2, there is perhaps 8 feet of marble, 20 feet of ore (garnet, diopside, and chalcopyrite or their oxidation products), and 25 feet of garnet rock, between the granite porphyry and the unaltered limestone. In the north ore shoot above the Alberta tunnel the blue limestone and granite porphyry were observed in contact with no evidence of metamorphism along the border of either rock. There is an excellent exposure of this kind in the road cut about 100 feet east of the lower tram station.

The several localities cited above serve to illustrate the peculiarities of distribution of the marble along the contact of the limestone and the granite porphyry, a distribution in no wise related to observed differences in the chemical or physical composition of either rock. The observations are believed to indicate clearly that the metamorphism is due to something more than simply the heat effect of the newly injected magma on adjacent rocks. Other observations which serve to confirm this belief are recorded below. Partial analyses of the unaltered limestone appear on page 59.

Development of lime silicate rock.—The striking and most noteworthy feature of the distri-



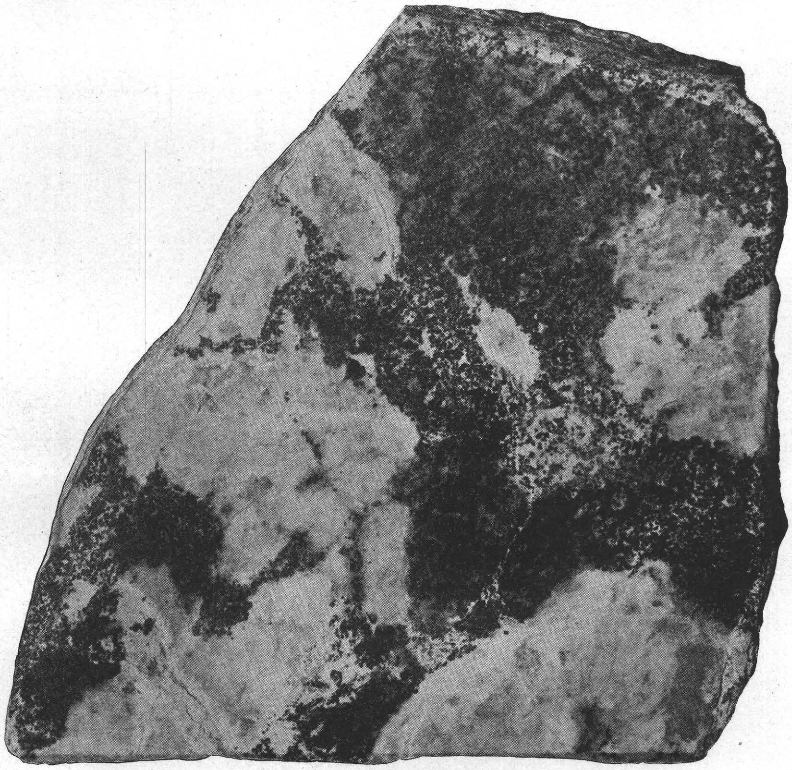
A. STRUCTURE IN GRANITE PORPHYRY WHICH EXTENDS BENEATH MARBLE (BEDS IN UPPER RIGHT CORNER) OF WHITE KNOB, ALDER CREEK DISTRICT, IDAHO.



B. WHITE KNOB, ALDER CREEK DISTRICT, IDAHO.

View from northeast.

A



B

SPECIMENS OF CONTACT-METAMORPHIC ROCK FROM EMPIRE MINE, ALDER CREEK DISTRICT, IDAHO.

A. Wollastonite (white) separated from blue limestone by a band of pale-blue marble. Natural size.
B. Characteristic association of custerite (light) and magnetite. Natural size.

bution of the garnet rock is that all the larger areas lie within the main granite porphyry mass. Three exceptions only to this generalization were observed. Garnet occurs with magnetite in the Magnetite tunnel of the Champion group (see fig. 13, p. 102) and with copper ore in the small shaft on the north end of the Remonetization claim, and in three prospects about 500 feet down the east slope of White Knob. In the last-mentioned occurrence, which alone is worthy of further mention, the garnet mass, though poorly exposed, is lenticular in form and cuts across the bedding of the marmarized limestone as a dike or vein.

Of the areas of garnet rock within the granite porphyry those exposed in the underground workings of the Copper Bullion claim may be most readily studied. Here several hundred feet of development on the ore through a vertical distance of 200 feet clearly shows that a garnet zone borders the west end of the embayed block of limestone which extends into the Copper Bullion claim from the east. A typical section from the center outward shows blue limestone, white marble, metamorphic silicates, and copper minerals intergrown, dense metamorphic silicate rock, and granite porphyry. In places the outer silicate zone is absent and elsewhere the marble and igneous rock are in contact.

The stopes above the Alberta tunnel, the largest in the district, represent two groups about 600 feet apart and are bordered in most places by garnet rock. In the north set limestone appears in the north end of several floors, but in the south group the surrounding formation is entirely garnet rock and granite porphyry. Here, however, much of the silicate rock contains interstitial calcite similar in every respect to that found in the garnet and diopside rock, which is unquestionably of limestone derivation. Here also much of the silicate rock has a faint stratiform structure, owing to slight differences in the relative abundance of garnet and diopside and to the size of the crystal grains, which is believed to indicate bedding inherited from replaced limestone.

The two principal groups of garnet shoots in the Alberta workings are clearly related to a fault which strikes N. 20°–30° E. and dips 50°–60° SE. The fault shows clearly in crosscuts Nos. 2, 4, 6, and 7 from the Alberta tunnel, at several places in the south group of stopes, and locally in the walls of the north stopes. It also is followed for about 600 feet by the 300-foot tunnel at a level 400 feet above the Alberta tunnel. In the north tunnel, 117 feet above the 300-foot tunnel, it is only recognized in the last west crosscut, the tunnel being driven in its hanging wall. The fault plane is characterized by a gouge and crushed zone from a few inches to several feet wide wherever it crosses the granite porphyry or the limestone, but within the ore or the lime silicate rock it is nowhere conspicuous.

These relations are interpreted to mean that the localization of garnet shoots in the Alberta workings is due both to the influence of included blocks of limestone now completely transformed and to the presence of a fault which for convenience may be called the Alberta fault.

Discussion of analyses.—Analyses have been made both of the limestone and the secondary silicate rock resulting from it in order to see what changes accompanied the metamorphism. As is discussed in another section (p. 71) volume changes during the transformation are negligible. It is necessary, therefore, in the following discussion to know the density of the rock types and the percentage of constituents in them in order to determine gains and losses. The percentage of any constituent multiplied by the density of the rock gives the number of grams of that constituent to the cubic centimeter. Thus the number of grams of the several constituents in the original and in the derived rocks affords an easy basis for comparison. In the following tables and figures this number is multiplied by 100 to bring the volume to a scale convenient for plotting and to reduce the significance of fractions. The method here used for plotting the gains and losses has the advantage over diagrams commonly used in that areas are proportional to each other, difference in density is shown to scale, and a progressive change involving several analyses may be represented.

Analyses of the fresh limestone and products resulting from it are shown below and are accompanied by diagrams illustrating the gain or loss of each constituent. (See fig. 9.)

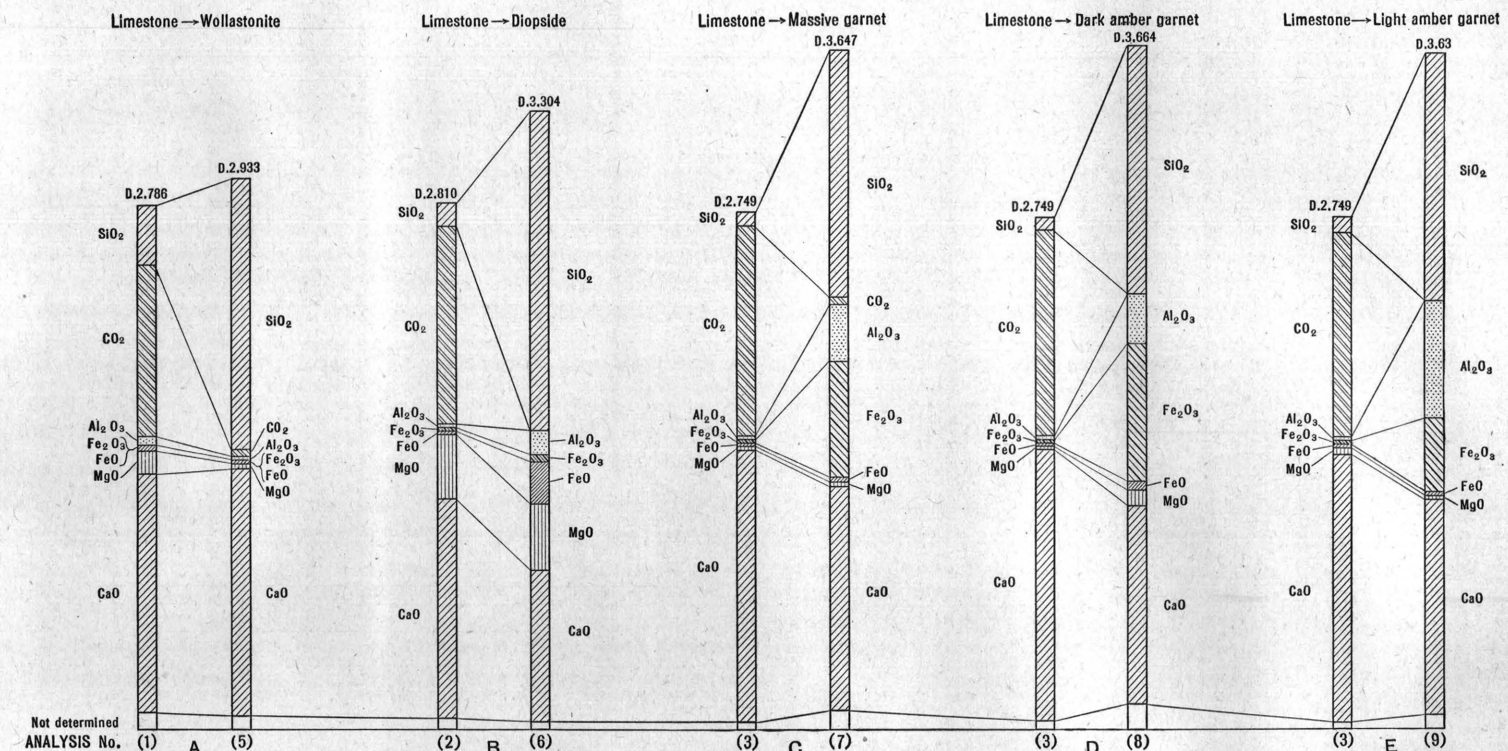


FIGURE 9.—Diagrams illustrating gains or losses in exomorphism. Gain or loss of each constituent is shown in grams in the transformation of 100 cubic centimeters of limestone to the same volume of secondary silicate rock. Scale: 1 inch=100 grams.

Analyses of limestone and silicate rocks derived from it.

	1	2	3	4	5	6	7	8	9
SiO_2	11.02	3.92	2.84	1.67	50.47	51.55	36.92	36.57	37.07
Al_2O_3	.90	.72	.18	.30	.45	4.00	8.75	7.56	17.42
Fe_2O_3	.24	.04	.13	.16	.16	1.02	16.85	20.34	10.81
FeO	.08	.26	.09	.08	.10	6.65	.50	1.24	.68
MgO	4.73	12.72	1.03	.48	1.17	11.38	.17	2.10	.51
CaO	47.39	42.14	54.14	53.71	45.99	24.23	33.71	30.20	32.77
Na_2O						.38	.31		
K_2O						.18	.21		
H_2O-						.14	.21	.30	
H_2O+						.25	.39	.54	.14
TiO_2						.32	.26	.20	.39
CO_2	33.71	38.98	41.28	41.89	.69	.0	.95	.0	
P_2O_5						.24	.30	.23	
MnO						.30	.67	.60	
	98.07	98.78	99.69	98.29	99.03	100.64	100.20	99.88	99.79
Specific gravity (lump)	2.786	2.810	2.749	2.728	2.933	3.304	3.647	3.664	[a] 3.63

[a] Density computed from the analysis.

Gain or loss of each constituent in grams per 100 cubic centimeters.

	1→5	2→6	3→7	3→8	3→9
SiO_2	+117.14	+159.10	+126.96	+126.04	+126.75
Al_2O_3	− 1.19	+ 11.18	+ 31.44	+ 27.17	+ 62.73
Fe_2O_3	− .19	+ 3.25	+ 61.14	+ 74.08	+ 38.88
FeO	+ .07	+ 21.21	+ 1.55	+ 4.27	+ 2.20
MgO	− 9.78	+ 1.81	− 2.21	+ 4.85	− 1.02
CaO	+ 2.54	− 38.45	− 25.84	− 38.35	− 29.92
CO_2	− 92.00	−109.53	−110.05	−113.52	−113.52
	+ 16.59	+ 48.57	+ 82.98	+ 84.54	+ 86.10

1. Limestone, Cave tunnel, Champion group.
2. Limestone, first bend from portal in Alberta tunnel.
3. Limestone, near first right lateral No. 4 crosscut, Alberta tunnel.
4. Limestone, near first lateral No. 3 crosscut, Alberta tunnel.
5. Wollastonite, opposite side of same hand specimen as No. 1.
6. Diopside, near second lateral No. 3 crosscut, Alberta tunnel.
7. Massive garnet 100 feet south of No. 5 crosscut, Alberta tunnel. Index of refraction 1.82–1.83. Maximum birefringence 0.01±0.003.
8. Dark amber-colored garnet crystals 1,500 feet northwest of Copper Bullion tunnel. Index of refraction 1.840± 0.003.
9. Light amber-colored crystals; Kemp, J. F., and Gunther, C. G., The White Knob copper deposits, Mackay, Idaho: Am. Inst. Min. Eng. Trans., vol. 38, p. 286, 1908.

Specimens 1 to 5 analyzed by W. C. Wheeler; 6 to 8 by Chase Palmer; 9 by Cyril Knight.

Many more combinations of the analyses are possible than are shown by the diagrams, but these are believed to be the most reasonable. It is possible, however, to recombine the columns mentally, as all are plotted on the same scale. In the development of wollastonite from limestone the substitution of silica for carbon dioxide alone is important. In the formation of diopside from a magnesian limestone the same substitution is important, but alumina and ferrous iron are added and calcium oxide partly extracted. The development of the several types of garnet implies a great addition of silica, alumina, and ferric iron along with a noteworthy loss of calcium oxide and the essential elimination of carbon dioxide. The different types of garnet depend on the relative amounts of ferric iron and alumina added.

The great fact brought out by the analyses, however, is the enormous amount of silica, alumina, and iron which have been added to the contact zone during metamorphism. Under another heading (p. 71) relations are considered which lead to the conclusion that the magma supplied this material.

ENDOMORPHISM.

General features.—The granite porphyry itself is completely transformed into garnet rock in many places, the localization of it being even more erratic than that of limestone derivation. In general it seems true that the garnet rock only occurs adjacent to the limestone, although many places were observed where the limestone had been intensely metamorphosed without the igneous rock having been affected. (See fig. 6, p. 48.) Where the silicate rock is bordered by granite porphyry the contact is locally much more irregular in detail than where it is bordered by marble, though the general outline is more regular. In many places stringers of garnet-diopside-chalcopyrite rock have been followed out along joints 10 to 20 feet into the granite porphyry. In places at the intersection of cross joints they open out into bunches of ore of minable size. The transition from silicate rock to granite porphyry in such situations is locally complete within a few millimeters, but elsewhere the transition zone is 2 or 3 feet wide. Adjacent to the contact diopside is abundantly developed in the igneous rock; near by after all the original minerals, farther away only after the biotite and hornblende, the hornblende being replaced first. Figure 8 (p. 49) shows a common relation of garnetiferous ore to the granite porphyry in the Copper Bullion workings. It also shows the influence of joints in determining points of maximum replacement.

Along the fault exposed in the Alberta workings the igneous rock has been transformed into garnet-diopside rock in many places. Here also occur irregular extensions of the metamorphic silicates into the igneous rock along joints with enlargements at the intersection of cross joints. Also in many places granite porphyry, much coarser in texture than the normal marginal facies, abuts the calcium silicate rock. Elsewhere kidney-like protuberances of the silicate minerals extend into the igneous mass and again (as in fig. 3) great bodies of ore cut sharply across the contact. Plate XIV illustrates the sharp transition seen in places from garnet rock into the granite porphyry which it replaces. Five thin sections were cut from the larger specimen, three across the contact and one near the outer edge on each side. The section of the granite porphyry contains orthoclase, albite, microcline, and oligoclase, together with remnants of biotite and hornblende, as the essential original minerals. Diopside in small diversely oriented crystals is abundant after the hornblende and biotite, in most places completely replacing the hornblende and leaving only small cores of the biotite. (See Pl. XIV, *C*.) The feldspar phenocrysts are comparatively fresh, though diopside replaces some of the oligoclase. Throughout the groundmass finely divided diopside is uniformly present. No garnet was recognized, but augite may occur. The slide from the opposite edge of the specimen is made up of garnet, diopside, a little tremolite, and even less fluorite. The diopside occurs principally as minute grains, some of which are so grouped as to suggest the shape of a basal section of hornblende and others the outlines of biotite. Though garnet is here the most abundant mineral a great deal of finely divided diopside is scattered through it. The tremolite, and possibly also some wollastonite, is intergrown with the diopside in many places, but locally it occurs in little veinlets which cross the other minerals. Fluorite is confined to veinlets. The three slides which cross the contact show on opposite ends conditions similar to those described above. The immediate line of contact is marked by a wavy band of dense garnet, which grades back into garnet rock in which crystal outlines are more readily recognized. In one place a feldspar phenocryst is truncated by the garnet, the continuation of the feldspar in the garnet being marked by finely granular diopside.

The order of replacement during endomorphism seems to be hornblende, biotite, quartz, plagioclase, orthoclase, phenocrysts of the last two minerals remaining until the groundmass is almost completely changed. The order of formation of the replacing minerals is diopside, garnet, tremolite, fluorite. In no place were metallic minerals recognized in garnet-diopside rock that is clearly derived from granite porphyry, though owing to the difficulty in distinguishing such rock in most places but little weight should be given to the observation.

Discussion of analyses.—The transition from diopsidized granite porphyry into garnet rock is very abrupt, as shown by the two hand specimens illustrated in Plate XIV, *A*, *B*, but the transition zone from fresh granite porphyry to that which contains large amounts of secondary diopside extends over many feet. The specimen of altered granite porphyry which was analyzed probably represents the maximum development of diopside before the beginning of garnet replacement. The specimen of garnet rock here represented is probably derived from limestone, but as in the hand specimen and in the thin section it is impossible to distinguish it from other specimens clearly derived from granite porphyry, a separate analysis was not believed to be warranted. The analysis of granite porphyry represents a perfectly fresh rock.

Analyses of fresh and altered granite porphyry and massive garnet.

[Chase Palmer, analyst.]

	Analyses.			Gain or loss in grams per 100 cubic centimeters.		
	10	11	7	10→11	10→7	11→7
SiO_2	71. 26	70. 18	36. 92	−2. 64	− 52. 13	− 49. 49
Al_2O_3	13. 94	12. 97	8. 75	−2. 35	− 4. 53	− 2. 18
Fe_2O_3	1. 01	. 82	16. 85	− . 49	+ 59. 40	− 59. 89
FeO	1. 35	. 86	. 50	−1. 28	− 1. 72	− . 44
MgO	. 67	. 95	. 17	+ . 74	− 1. 14	− 1. 88
CaO	1. 64	3. 98	32. 71	+6. 18	+119. 83	+113. 65
Na_2O	3. 96	2. 89	. 31	−2. 83	− 9. 30	− 6. 47
K_2O	4. 35	5. 40	. 21	+2. 78	− 10. 74	− 13. 52
H_2O-	. 26	. 18	. 21	− . 21	+ . 05	− . 27
H_2O+	. 55	. 29	. 39	− . 69	− . 01	− . 68
TiO_2	. 56	. 54	. 26	− . 05	− . 52	− . 49
P_2O_5	. 10	. 26	. 30	+ . 42	+ . 84	+ . 42
F	. 018	. 035	....	+ . 05	....	....
MnO	. 55	. 55	. 67	+ . 01	+ 1. 02	+ 1. 03
CO_2	....	....	. 95	....	+ 3. 49	+ 3. 49
	100. 22	99. 91	100. 20	+ . 36	+104. 53	+104. 17
Specific gravity (lump)	2. 637	2. 64	3. 647	....	....	....

10. Granite porphyry, 400 feet northeast of mineral monument No. 1.
11. Altered granite porphyry near mouth of second lateral No. 4 crosscut, Alberta tunnel.
7. Massive garnet, Alberta tunnel, 100 feet south of No. 5 crosscut. Same as analysis 7, p. 59.

It is very striking (fig. 10) that in the diopsidization of the granite porphyry the only important addition is lime, which in part seems to replace soda. In the further transition to massive garnet, however, there are notable additions of both lime and ferric iron, accompanied by a proportionally much smaller loss of silica, soda, and potash. Throughout the transformation, alumina, ferrous iron, and magnesia remain essentially constant. The principal difference between the development of garnet from granite porphyry, and from limestone, as previously described, is that in the granite porphyry lime has been added in large amounts and silica subtracted, and in the limestone silica has been largely added and lime remained constant or was reduced. The first metamorphism requires primarily a supply of lime and iron, the second a supply of silica, alumina, and iron. These requirements, which are in part compensating, would seem to favor the metamorphism of both the igneous and calcareous rocks where they are adjacent.

RELATIVE IMPORTANCE OF ENDOMORPHISM AND EXOMORPHISM.

Satisfactory criteria for distinguishing the products of endomorphism from those of exomorphism in these deposits have not been recognized. Apatite has not been found in the silicate rock unquestionably derived from limestone, whereas it does occur in that which replaces the granite porphyry. Titanite is likewise confined to the granite porphyry so far as observed. Both these minerals, however, are common in contact-metamorphic deposits, and to rely on them as definite criteria might be misleading. Locally the lime silicate rock has inherited in part the pattern of the igneous rock and elsewhere it shows the bedding structure of the limestone, but such features were recognized only in the border phases of the metamorphism. In many places the metamorphic silicates are set in an abundant matrix of calcite, but this is common only near a marble contact, where the derivation from limestone is otherwise apparent. All these features fail or become unreliable in the broad zones of most intense metamorphism, many of which

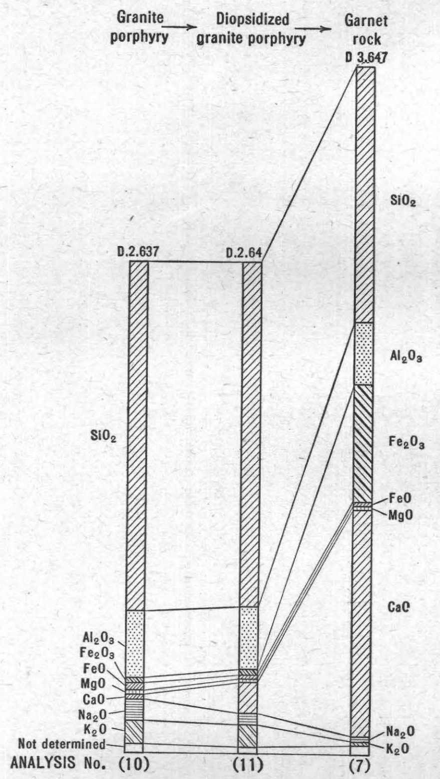


FIGURE 10.—Diagrams illustrating gains or losses in endomorphism. Gain or loss of each constituent is shown in grams in the transformation of 100 cubic centimeters of granite porphyry to the same volume of diopsidized granite porphyry and this to massive garnet rock. Scale: 1 inch=100 grams.

have on the one side garnet rock clearly developed from limestone, and on the other that developed from granite porphyry. Broad relations only can be considered in determining the relative importance of the exomorphism and endomorphism, but these point to exomorphism as being much the more important quantitatively. Where bodies of silicate rock cross the contact, as in figure 1, they invariably attain their maximum development in the limestone; the number of places also where the stopes are near limestone is far greater than the number where they are close to the porphyry. The general fact that endomorphism of this sort is uncommon as compared with similar exomorphism argues further, though probably weakly, for the same conclusion. Another line of attack is a determination of the amount of calcium oxide available for exomorphism after endomorphism is complete. This method of course involves the assumption of essentially constant volume in the limestone block, an assumption fully warranted, however, because the garnetization clearly took place after the solidification of the igneous rock adjacent. Such calculations, on assuming the maximum range in specific gravities and composition, show that not more than 20 per cent of the lime in the original block was expelled and thus was available for the development of garnet and diopside in the adjacent igneous rock. Thus, on assuming no escape of lime and no supply from the rising solutions, a maximum of not over 20 per cent of the garnet rock appears to be derived from granite porphyry; 10 per cent is probably a fair average.

HYDROTHERMAL METAMORPHISM.

The products of normal hydrothermal metamorphism are meager in these deposits. Sericite is present in many of the specimens of the granite porphyry from near the surface but is completely lacking in those taken at a depth of a few hundred feet. Chlorite similarly is confined to the surface rocks. In this particular these deposits are very different from those at Clifton-Morenci,[1] and Silverbell,[2] though similar to those at Dolores,[3] and San José.[4]

MINERALS DEVELOPED DURING IGNEOUS METAMORPHISM.

The mineralogy of the contact deposits is described elsewhere (pp. 49–55), so that here only the minerals particularly related to the igneous metamorphism will be discussed.

Garnet represents perhaps 85 per cent of the intensely metamorphosed rock. The common variety makes up a massive, in many places aphanitic, rock of peculiar greasy luster, which in most specimens contains minute veinlets and interstitial areas of calcite. Under the microscope this mineral, together with diopside, wollastonite, and quartz are seen to be the common impurities. Apatite and titanite have been detected in a few sections. Locally the garnet occurs as distinct crystals (see fig. 11),

[1] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, p. 110, 1905.

[2] Stewart, C. A., The geology and ore deposits of the Silverbell mining district, Ariz.: Am. Inst. Min Eng. Trans., vol. 43, pp. 265–266, 1912.

[3] Spurr, J. E., Garrey, G. H., and Fenner, C. N., Study of a contact-metamorphic ore deposit: Econ. Geology, vol. 7, No. 5, p. 481, 1912.

[4] Kemp, J. F., The copper deposits at San Jose, Tamaulipas, Mexico: Am. Inst. Min. Eng. Trans., vol. 36, p. 194, 1905.

most of which agree in color with the massive garnet rock, although some are distinctly lighter and others are much darker. The lighter variety appears to be characteristic of the margins of metamorphic areas, but the darker one is commonly associated with magnetite in veinlets which in many places cut other garnet rock. Thin sections of the

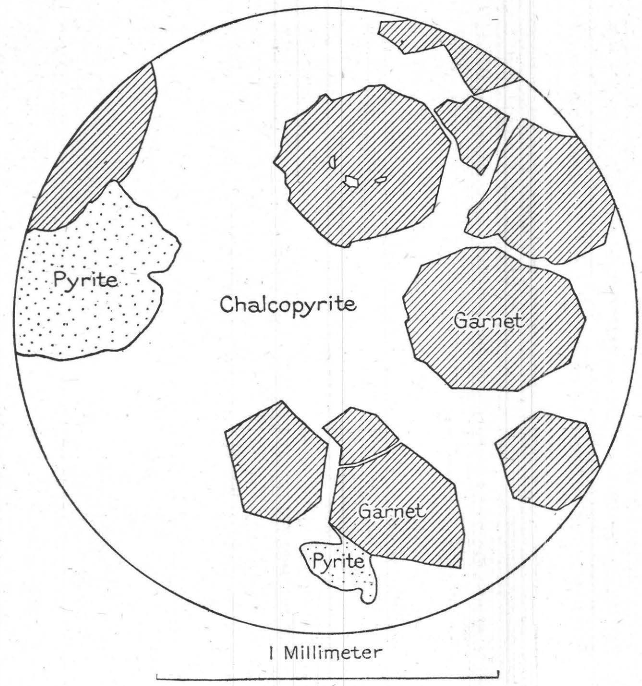


FIGURE 11.—Euhedral garnet in matrix of chalcopyrite. Chalcopyrite believed to have replaced residual calcite. ×90.

Composition of garnet rock.

	Analyses.					Approximate quantity of minerals.			
	7	12	8	9		7a[a]	12a	8a[a]	9a
SiO_2	36.92	37.79	36.57	37.07	Grossularite ($3CaO.Al_2O_3.3SiO_2$)	35.55	47.82	21.60	69.26
Al_2O_3	8.75	11.97	7.56	17.42	Andradite ($3CaO.Fe_2O_3.3SiO_2$)	53.49	44.16	64.54	21.13
Fe_2O_3	16.85	15.77	20.34	10.81	Almandite ($3FeO.Al_2O_3.3SiO_2$)	1.14	2.99	2.87	1.61
FeO	.50	1.31	1.24	.68	Pyrope ($3MgO.Al_2O_3.3SiO_2$)	.56	1.31	6.95	1.44
MgO	.17	.37	2.10	.51	Spessartite ($3MnO.Al_2O_3.3SiO_2$)	1.55	.68	1.39	...
CaO	33.71	32.57	30.20	32.77	Wollastonite	2.80	...	.81	...
Na_2O	.31	...	...	...	Hematite	...	1.90	...	4.25
K_2O	.21	...	...	...	Quartz	.95	1.32	.66	...
H_2O-	.21	.09	.30	.14	Calcite	2.16	...	...	...
H_2O+	.39	...	.54	.39	Apatite	.55	...	.50	...
TiO_2	.26	...	.20	...	Titanite	.32	...	.43	...
CO_2	.95	...	...	...	Kaolin	...	...	...	2.61
P_2O_5	.30	...	.23	...					
MnO	.67	.31	.60	...					
	100.20	100.18	99.88	99.79		99.07	100.18	99.75	100.30
Index of refraction.	1.82–1.83[b]	...	1.840±0.003	...	Water	.60	.09	.84	...
						99.67	100.27	100.59	

[a] In the earlier publication (Econ. Geology, vol. 9, No. 4, pp. 338–339, 1914) these recast analyses and No. 6a (p. 64) were given in percentages of mineral molecules instead of percentage of minerals by weight, as above.

[b] Maximum birefringence 0.01±0.003.

7. Normal massive garnet, Alberta tunnel, 100 feet south of No. 5 crosscut; Chase Palmer, analyst.
12. Massive garnet; Kemp, J. F., and Gunther, C. G., The White Knob copper deposits, Mackay, Idaho: Am. Inst. Min. Eng. Trans., vol. 38, p. 286, 1908; T. T. Read, analyst.
8. Dark amber-colored garnet, distinct crystals, 1,500 feet northwest of Copper Bullion tunnel; Chase Palmer, analyst.
9. Light amber-colored garnet; Kemp, J. F., and Gunther, C. G., op. cit.; Cyril Knight, analyst.

lighter variety, which in most places is embedded in calcite, show a clear garnet which commonly has no pronounced zonal growth and contains but few inclusions. The later, darker garnet in many places contains irregular cores of magnetite, in which zonal growth appears to be characteristic. Four analyses are available, two of which appear in the paper by Kemp and Gunther. Two of the analyses are of the massive garnet, one is of the dark amber-colored garnet of later development, and the other, which is described by Kemp and Gunther as "light amber-colored garnet," is believed to represent the light-colored garnet crystals embedded in the calcite about the margins of massive garnet areas.

Each of the garnet analyses in the table is recast in order to further emphasize the observation of Kemp and Gunther that the andradite molecule enters largely into the composition of all the forms present in the Mackay deposits. It would seem that in the massive garnet andradite is even more abundant than grossularite. Andradite comprises 60 per cent of the dark amber-colored crystals, but only 21 per cent of the light amber-colored crystals, which suggests that in these deposits color is a fair criterion for determining the approximate type of garnet. Andradite is of particular interest in contact deposits because of the large amount of iron which it contains.

Pyroxene is second to garnet among the contact-metamorphic minerals of the deposits. It occurs in the garnet rock, as minute crystals in the marble, after hornblende and biotite in the endomorphism of the granite porphyry, and as a dense green aphanitic rock; locally it occurs as a white, marble-like rock composed almost entirely of wollastonite. Analysis was made of both the dark and the light-colored massive pyroxene rock. With that of the dark rock given below is presented one published by Kemp and Gunther.

Thin sections of this material reveal diopside and a very little hedenbergite and augite but no wollastonite. In recasting the analyses into approximate quantity of minerals, therefore, no allowance has been made for the pure lime silicate, pyroxene. It is noteworthy that considerable iron and alumina are here represented, although the amount is far less than that in the garnet.

Composition of dark-colored pyroxene rock.

	Analyses.			Approximate quantity of mineral molecules.		
	6	13		6a	13a	
SiO_2	51.55	45.85	Pyroxene:			
Al_2O_3	4.00	12.21	CaO, SiO_2	37.91	54.98	Diopside.
Fe_2O_3	1.02	2.15	MgO, SiO_2	24.84	8.70	
FeO	6.65	2.49	FeO, SiO_2	12.30	4.62	Hedenbergite.
MgO	11.38	8.70	CaO, SiO_2	11.29	4.06	
CaO	24.33	28.54	MnO, SiO_2	.52		
Na_2O	.38		MgO, Al_2O_3, SiO_2	6.34	24.04	Augite.
K_2O	.18		MgO, Fe_2O_3, SiO_2		3.33	
H_2O-	.14		Na_2O, Fe_2O_3, SiO_2	2.74		
H_2O+	.25		K_2O, Al_2O_3, SiO_2	.30		
TiO_2	.32		Apatite	.49		
CO_2	.00		Titanite	.78		
P_2O_5	.24		Water	1.26		
MnO	.30		Quartz	1.20		
	100.64	99.94		99.97	99.73	

6. Massive pyroxene rock, near second lateral No. 3 crosscut, Alberta tunnel; Chase Palmer, analyst.
13. "Diopside rock"; Kemp, J. F., and Gunther, C. G., op. cit., p. 288; T. T. Read, analyst.

The white pyroxene rock was powdered and examined in index solutions in order to determine what minerals should be recognized in recasting the analysis. Wollastonite is the essential mineral, but diopside, augite, calcite, and quartz may be identified. Hedenbergite is assumed to be present because of the ferrous iron. In the formation of this mineral from the limestone much silica must be introduced, but essentially no iron or alumina.

From the foregoing discussion and also from the diagram on page 58, it appears that the light pyroxene or wollastonite rock requires a large addition of silica. The dark pyroxene or diopside rock requires a large addition of silica and noteworthy amounts of both iron and alumina. In the garnet rock, however, additions are most important, and here silica, alumina, and iron are all added in large amounts. As garnet is by far the predominant mineral in the deposits the additions which it implies should be considered typical of the Mackay contact zones.

Composition of white pyroxene rock.

[W. C. Wheeler, analyst.]

	Analysis (5).		Approximate quantity of mineral molecules (5a).	
SiO_2	50.47	Pyroxene:		
Al_2O_3	.45	CaO, SiO_2	91.24	Wollastonite.
Fe_2O_3	.16	MgO, SiO_2 CaO, SiO_2	5.61	Diopside.
FeO	.10			
MgO	1.17	FeO, SiO_2 CaO, SiO_2	.23	Hedenbergite.
CaO	45.99			
CO_2	.69	MgO, Al_2O_3, SiO_2 MgO, Fe_2O_3, SiO_2	.89	Augite.
	99.03	Calcite	1.75	
		Quartz	.28	
			100.00	

5. Massive wollastonite resembling the fine-grained white marble. From Case tunnel, Champion group.

TWO STAGES OF METAMORPHISM.

Two distinct stages of metamorphism are believed to be recorded in the Mackay deposits. These stages may be grouped as contact metamorphism at the time of intrusion, and contact metasomatism subsequent to intrusion. That the development of the lime silicate rock took place in the main after the solidification of the outer few hundred feet of the batholith is perfectly clear. It is fairly certain also that most of the marmarization occurred at an earlier time. Whether or not there was a distinct break between the two stages, however, is not definitely determinable from available evidence.

The great marble mass of White Knob, as already suggested (p. 56), affords evidence that at the time of its marmarization physicochemical conditions were essentially uniform in all its parts. There is absolutely no evidence that the metamorphosing solutions were fed to it from local vents in the granite porphyry, but there are indications that it was supplied with heat and vapor similarly at all parts of its contact with the igneous rock. It is believed that vapors rising from the entire upper surface of the intrusion caused the transformation. This conception however, is very different from that which is thought to account for the garnet dike that traverses the marble beds on the east slope of White Knob. Here the escaping solutions were supplied locally along a nearly vertical fissure, and although they worked upward for 300 or 400 feet, changing the marble to garnet-magnetite rock, they did not work laterally more than a few feet. It is also worthy of note that vertical portions of the contact of the limestone and granite porphyry are not marmarized for more than a few inches, whereas the great segment of the roof represented by White Knob is completely transformed to marble throughout its area of about a square mile.

Blocks of limestone engulfed in the magma show a rather persistent marble aureole which ranges in width from perhaps 2 feet to 100 feet or more; locally it is absent. This general distribution of marble, though erratic, is far more regular than that of the silicate rock, as will now be shown.

The distribution of the garnet rock is exceedingly erratic, but in many places its localization is clearly due to faults and joints in the granite porphyry, as in the Alberta and Copper Bullion tunnels. In the Copper Bullion tunnel ore replaces the igneous rock along joints and opens out locally into minable bodies at the intersection of cross joints. (See fig. 8.) In the Alberta tunnel a distinct fault has unquestionably directed the ore-bearing solutions. That the metamorphism was later than the solidification of at least the outer part of the magma is also proved by hand specimens, which show garnet that replaces the igneous rock at joints and along irregular surfaces. One specimen in the collection (Pl. XIV, *B*, p. 60) came from No. 6 crosscut of the Alberta tunnel, at a point 700 feet below the surface and at least 200 feet from the periphery of the batholith. Another specimen (Pl. XIV, *A*) taken near the Iron tunnel came from 1,000 feet within the granite porphyry area, although here the record of the vertical distance to the roof of the batholith is obliterated by erosion.

From these observations it is certain that the garnet-forming solutions, at least in major part, arose after the solidification and fracturing of the outer part of the batholith. That marmarization accompanied the intrusion is believed to be proved by the uniform metamorphism of White Knob. Furthermore, the general persistence of marble about the periphery of the included blocks favors this belief. The development of marble, however, was not merely a heat effect, for it is noticeable that vertical portions of the contact are not affected as extensively as where the limestone overlaps the igneous rock. Heat probably radiated almost equally in all directions, but vapors would tend to escape upward both by reason of their low density and because the fracturing of the roof incident to intrusion would determine lines of easy passage toward the surface. These solutions are conceived to have been essentially water vapors, for no evidence of accessions of material has been noted in connection with this earlier metamorphism. The sparse and minute crystals of diopside, tremolite, and wollastonite in the White Knob marble are believed to represent only impurities in the original limestone.

In conclusion it is believed that two types of solutions escaped from the magma—the one before and during the consolidation of an outer shell and the other after its consolidation and fracturing. It is believed that the earlier solutions caused only a recrystallization of the limestone, whereas the later solutions transformed much of the limestone into lime silicate rock. The earlier solutions were characterized by water vapor; the later ones by silica, alumina, iron, and fluorine, in addition to water vapor. Whether or not the earlier solutions graded into the later ones and thus whether the two represent end stages in a continuous period of magmatic emanation is not susceptible of rigorous proof. It is the opinion of the writer, however, that two separate and distinct epochs of magmatic emanation are represented, and about this concept he has attempted to formulate a hypothesis to account for the relations illustrated in the Mackay deposits.

PHENOMENA DUE TO OXIDATION AND RELATED PROCESSES.

DEGREE OF OXIDATION.

Oxidation is well advanced in most parts of the deposits exposed by the mine workings, and in the south Alberta shoot it extends to the lowest level in the mine, 700 feet below the surface. Only in stope No. 3 in the Copper Bullion and in the north Alberta shoot above and below the 700-foot tunnel level, have sulphide ores been found in minable quantities.

Chrysocolla is present everywhere as the chief product of oxidation. It is of diverse color and contains widely different amounts of copper, iron, and manganese in different places. Included in it are blebs and interrupted bands of malachite, azurite, and other much less abundant secondary copper minerals. (See Pl. XV, *A*.) The chrysocolla ranges from reddish yellow through brown to brownish black; rarely it is green to light blue. The green variety has a vitreous luster and is crystallized, but the reddish-yellow to brownish-black variety is dull and in most places amorphous or cryptocrystalline. Partial analyses of the two varieties of chrysocolla appear on page 51. It is noteworthy that their chief difference is in the amount of ferric iron which they contain, and that in water, silica, and cupric oxide they are alike.

RELATION OF OXIDATION TO GROUND-WATER LEVEL.

In the Mackay deposits oxidation extends several hundred feet below ground-water level. Near the outcrops water stands in workings less than 100 feet deep, but ground waters circulate to much greater depths. The deposits crop out at elevations 2,000 to 2,700 feet above the near-by valley of Big Lost River, which, with, that of its principal tributary, Cliff Creek, determines low points in the water table of the district. The position of the water table locally at much higher elevations is determined by a balance between the amount of water which enters from above and that which escapes along the major arteries and evaporates from the lower slopes. Thus between high and low points in the water table there must be in general a noteworthy circulation of ground water, and therefore the possibility of oxidation throughout this range in depth.

The south Alberta shoot has been explored to a vertical depth of 700 feet and the ores are oxidized throughout. At just what level water would stand in this shoot is not known, as the Alberta tunnel drains it, but near-by shafts contain water at a depth of 30 or 40 feet, and at the time of visit water stood in underhand stopes from the "big quarry" on the hill above it. On the other hand, the north Alberta shoot, only 600 feet away and close to the intricately jointed limestone, contained sulphide ore, in most places below a depth of about 50 feet. Likewise in the Copper Bullion tunnel nearly vertical shoots of primary and sulphide ore occur side by side. To what depth this diversity in the character of the different ore shoots will continue it is impossible to foretell. It seems certain, however, that the relative amount of sulphides will continuously increase, for with increasing depth below the level of saturation the movement of the waters will be more and more along particular paths, and the amount of dissolved oxygen in the water will be less and less by reason of the increasing amount of oxidizable material through which it passes.

PRODUCTS OF OXIDATION.

The most noteworthy feature of the oxidized ores is the prevalence of cryptocrystalline and amorphous materials in them. The dominant mineral form is chrysocolla, but under that name is included amorphous to microcrystalline material composed of different amounts of iron, copper, silica, and water, with occluded alumina. (See Pl. XV, *B*.) This sort of ore has resulted from the breaking down of garnet-chalcopyrite rock, apparently with the loss of very little material except sulphur and calcium. In the thin sections it is easy to observe all stages of oxidation, from those in which garnet, though retaining its crystal outlines and bands of zonal growth, is iron stained throughout and is bordered by areas of finely divided malachite in a base of pale-blue chrysocolla, to those characterized by radial groups of malachite, brochantite, chrysocolla, and zonally banded amorphous siliceous material, including bands and flecks of opal, jasper, ferric hydroxide, and chrysocolla. This extreme phase of oxidation is represented by most of the secondary ores. In one of the sections, which seems to be characteristic, cores of dense reddish-brown amorphous siliceous material are bordered by alternating light-brown and dark-brown layers, which have high indices of refraction and are composed in large part of hydrous iron oxide and silica. The dark layers are much narrower than the light ones, but both are continuous except where the nuclei are so close together that growth has resulted in mutual interference. External to them is a narrow band of fibrous chrysocolla, the individuals of which have parallel orientation normal to the surface they surround. Under crossed nicols these fibrous crystals react almost as one crystal. In places the concentric layer of fibrous chrysocolla is separated from the banded nuclei by fan-shaped groups and bands of acicular malachite crystals which radiate outward. On their inner side the fibers converge into a dense mass, separated from the outermost dark-brown amorphous band by a sharp contact, but outward they are intercalated with fibrous chrysocolla. Beyond the chrysocolla band, both here and where malachite is absent on its inner side, is an intimate mixture of malachite, or locally brochantite, and chrysocolla with calcite and opal here and there. Particularly here the crystals are radially disposed. In the sections in which brochantite replaces malachite in these interstitial areas, it occurs in spherical individuals, locally with an amorphous core surrounded by radiating crystals, and also in connected areas embedded in isotropic material, some of which is opal and the remainder is a pale-green copper-bearing siliceous substance, in part amorphous and in part cryptocrystalline. The radiating crystals themselves show a faint structure concentric with respect to the core, the alternating bands being of slightly different colors.

Several specimens consisting of a microscopic breccia of fresh pyrite cemented by oxi-

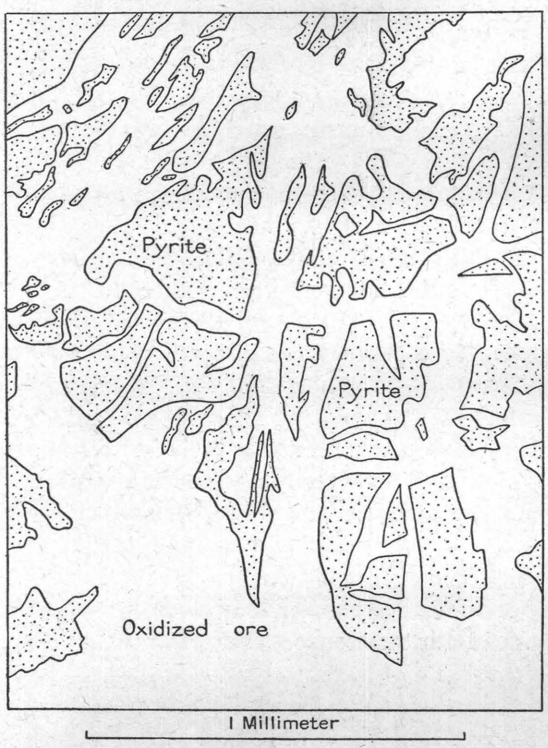


FIGURE 12.—"Bomb structure" in pyrite with interstitial chalcopyrite (?) completely oxidized.

dized ore are probably due to the breaking down of chalcopyrite in place. (See fig. 12.)

GENESIS OF THE SECONDARY ORES.

Features considered.—There are three principal features of the secondary ores which must be considered in a discussion of their genesis: (1) The seemingly meager transfer of material which accompanied their formation; (2) the great amount of amorphous and cryptocrystalline material in them; and (3) the microscopic radial and concentric disposition of many of the constituents.

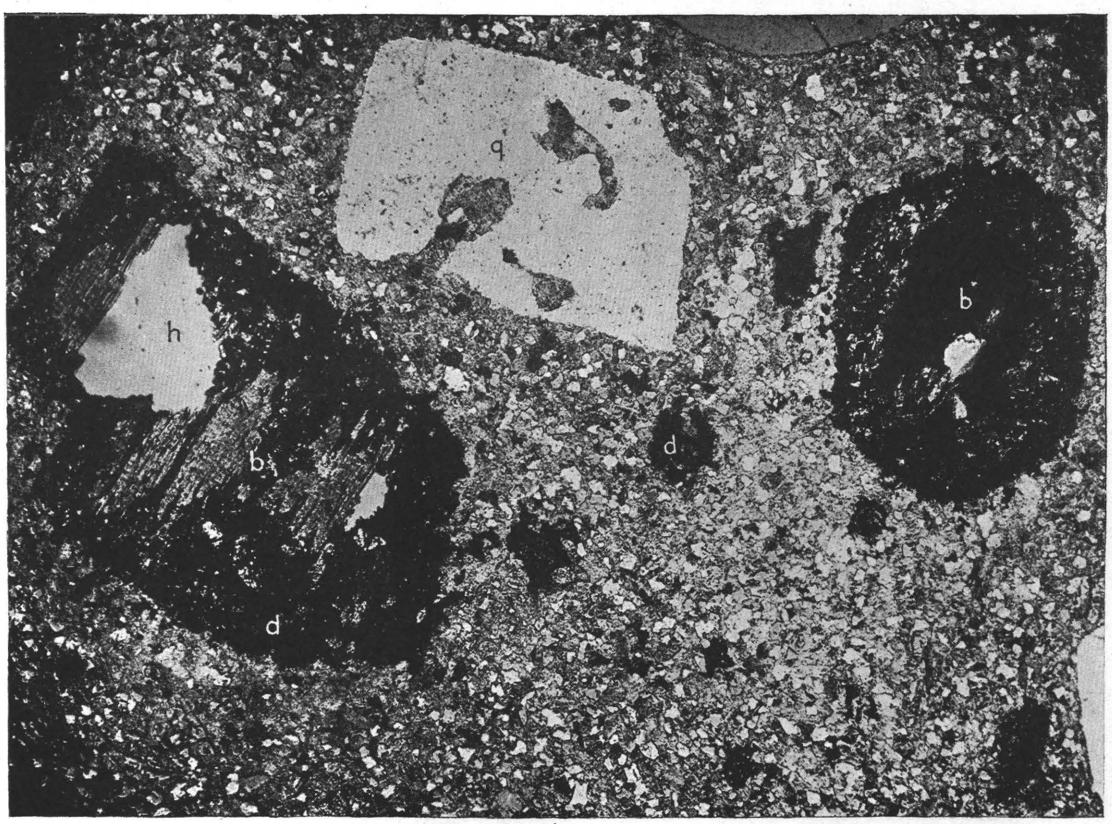
The close accord in the tenor of the primary and the secondary ores (p. 99) suggests that transfer of material during oxidation has not been important. This suggestion is supported both by the sparsity of secondary sulphides and by the absence of films and veinlets of secondary minerals in the primary and partly oxidized ores and in the wall rock. Furthermore, waters which trickle down through the stone do not deposit iron and do not contain sufficient copper to be detected by chemical tests.[1] In addition some of the chrysocolla ore retains the general crystal outlines of the garnet formerly present. The logical inference to be drawn from these several observations, as expressed by Kemp and Gunther,[1] appears to be that "once the copper passed into solution in the oxidation of the sulphides, it seems to have combined with silica to give the hydrated silicate and to have remained near its source." It is believed, furthermore, that this conclusion applies not only to the copper but also to other constituents of the garnet-chalcopyrite rock. A partial analysis of oxidized ore, comprising a heterogeneous assemblage of the yellow, brown, and black chrysocolla and included specks of malachite, azurite, and brochantite, reveals alumina, silicate, and iron in proportions comparable to those obtaining in the garnet rock. (See analyses 2, p. 51, and 7, p. 61.) Even if no material were removed, a closer accord with the original ore could not perhaps be expected in view of the small samples used in the analysis. The only direct evidence of material having been transported during oxidation is the occurrence of a few veinlets of gypsum in the walls and deep-lying ores and the absence of sulphur and the small amount of lime in the oxidized ore. (See Pl. XVI, *B*.) A negative suggestion, however, that material was removed lies in the notable increase in volume which probably accompanied oxidation and hydration, although the relative abundance of constituents of different density is so different in different places that it is impossible to evaluate it. If there was a noteworthy increase in volume, it would seem that something in addition to the sulphur and part of the lime must have been removed, but if so no traces of it were detected.

The second and third of the major features are considered together, because many of the concentric layers are amorphous (see Pl. XVII, *A*, *B*) and many of the acicular crystals of chrysocolla, malachite, and brochantite radiate from an amorphous core that consists

[1] Kemp, J. F., and Gunther, C. G., The White Knob copper deposits, Mackay, Idaho: Am. Inst. Min. Eng. Trans., vol. 38, p. 296, 1908.

A

B



C

SPECIMENS OF GARNETIZED GRANITE PORPHYRY FROM EMPIRE MINE, ALDER CREEK DISTRICT, IDAHO.

A. Garnet developed in joint planes. Specimen taken near Iron tunnel. Natural size. The dark band along the contact of the garnet and porphyry is due to a depression developed in polishing.

B. Specimen from Alberta tunnel, on crosscut No. 6, taken at a point 100 feet from the entrance. The dark area is garnet. Natural size.

C. Photomicrograph illustrating early stages of endomorphism. The section is taken from the granite porphyry in the specimen shown in *B*. Shows diopside (d) developing after biotite (b); q, quartz; h, hole in section. The core of biotite in the smaller phenocryst is at extinction. Crossed nicols. × 50.

largely of silica and iron hydroxide, and elsewhere they are grouped in an amorphous groundmass. The concentric and radial disposition of many of the constituents is particularly noteworthy, because the microscopic orbules are closely spaced throughout considerable masses of ore and therefore the arrangement can not be interpreted as crustification phenomena. Their character and distribution are entirely independent of any observed original structure. So far as they are crystalline, they have formed either from solution or from a gelatinous mixture resulting from the oxidation and hydration of the garnet-chalcopyrite ore. As about 80 per cent of the material is amorphous, however, it is inferred that the secondary ore minerals separated directly from a jelly which resulted from the setting of a colloidal solution which contained the several mineral elements. In the breaking down of a garnet gangue, colloidal matter may be produced in the form of hydrated gelatinous aluminum silicates, gelatinous silicic acid, and hydrated ferric oxide. Indeed it is believed that all these forms are represented by amorphous material now in the ore. The cores of dense material probably contain the aluminum and part of the silica and iron shown in the analysis. Alternating lighter and darker bands, principally of ferric hydroxide, and external to these the crystalline copper silicate, surrounds the cores. The copper silicate is apparently within the area of original chalcopyrite.

The minute zonal arrangement of the constituents of the secondary ore and the fact that so far as can be determined all parts of the mass contain copper indicates very definitely a rearrangement of material during the oxidation and hydration of adjacent areas of garnet and chalcopyrite. There is no indication, however, that the constituents, except sulphur and lime, moved more than a few millimeters, rarely perhaps a few centimeters. In general the thin sections suggest that copper tended to move into areas of garnet and that silica tended to move into areas of chalcopyrite as perhaps also did lime. Sulphur in the main disappeared, but iron accumulated along the border of garnet areas, probably from the garnet side, where abundant iron was present in the garnet, and from the chalcopyrite side, the latter inference being supported by the absence of iron minerals in many areas which formerly contained chalcopyrite. It seems likely that some iron was removed with the sulphur, though direct evidence that it wandered has not been recognized.[1]

Diffusion phenomena.—A banded or concentric arrangement of constituents has been rather generally interpreted to indicate a fluctuation in the character of material supplied. Recently, however, these features have been explained by rhythmic deposition, and it has been pointed out that colloidal media are favorable to the production and preservation of these structures, though they are not necessary.[2] The phenomenon has been studied in detail by R. E. Liesegang,[3] who discovered it in 1896. If a drop of solution of silver nitrate is placed on a plate coated with gelatin impregnated with potassium dichromate a series of concentric rings of silver dichromate will form at increasing distances from the center. Ostwald[4] explains the phenomenon as due to diffusion of the soluble silver salt outward until in a zone of supersaturation silver dichromate precipitates as a definite ring; further outward diffusion giving rise to other rings. The phenomenon is broadly a movement from points of higher to those of lower concentration.

In applying these general conceptions to the oxidized ores at Mackay it is necessary to consider the possibility of movement of copper into areas of garnet and of silica into areas of chalcopyrite. The occurrence of the copper throughout the amorphous material is readily explained by diffusion of this substance into a gelatinous mass and its zonal distribution by rhythmic precipitation. The migration of silica into areas of chalcopyrite where needles of chrysocolla now occur does not seem to be susceptible of this explanation without qualification. Silica existing in colloid solution may migrate from one point to another until equilibrium is established, but it can not, so far as is known, diffuse through a gelatinous membrane or precipitate. It follows that as silica occurs throughout the entire mass it probably was distributed during some early stage of oxidation when the mass existed as a hydrosol. The bands and "Liesegang rings" of chryso-

[1] Bibliographies of the literature on colloids appear in U. S. Geol. Survey Bull. 388, pp. 59-62, 1909, and in Fortschritte der Min., Krist. u. Pet., Band 3, pp. 32-37, 1913.

[2] Morse, H. W., and Pierce, G. W., Diffusion und Übersättigung in Gelatine: Zeitschr. physikal. Chemie, vol. 45, p. 589, 1903.

[3] Steinkopff, Theodor, Geologische diffusionen, Dresden and Leipzig, 1913, 180 pp., 44 text figs.; reviewed by Adolph Knopf, Econ. Geology, vol. 8, pp. 803-806, 1913.

[4] Ostwald, Wilhelm, Lehrbuch der allgemeinen Chemie, Aufl. 2, Band 2, Teil 2, p. 778, 1896-1902.

colla, however, can only be explained as diffusion phenomena through a gelatinous membrane or precipitate, and this diffusion probably took place at some later time. Apparently after the mass was in a gelatinous state iron also migrated somewhat and formed the alternating yellow and dark-red bands conspicuous in the thin sections. Aluminum, however, remained entirely within the original areas of garnet, and the thin sections offer no suggestion that it diffused.

In conclusion it is believed that but little migration of material accompanied the oxidation and hydration of the primary ore; that gelatinous compounds, characterized by an abundance of silicic acid and ferric hydroxide, were abundantly developed during oxidation and hydration; and that many of the microscopic features of the secondary ores may be explained most reasonably as phenomena of diffusion and rhythmic precipitation in gelatinous media. The presence of acicular crystals is not opposed to the conception of such media.

INTERPRETATION AND CONCLUSIONS.

QUESTIONS TO BE CONSIDERED.

The more vital questions confronting the student of contact-metamorphic replacement deposits at present are: (1) Do the lime silicates and ore minerals represent in large part contributions from the magma, or are they to be accounted for by a concentration of impurities in the original limestone? (2) Does the metamorphism occur at the time of intrusion or subsequently? (3) In a given deposit are there successive waves of metamorphism? (4) In general is there a progressive change in the composition of the metamorphosing solutions? (5) Is it possible to account for the contact rocks by a stimulation of meteoric circulation along the contact at the time of magma injection and during its period of cooling? These and many other questions should be considered by the student of contact-metamorphic deposits. Apparently no two deposits of this type have had precisely the same history, but they have so much in common that the evidence from local occurrences is of paramount value in testing general hypotheses.

The evidence afforded by the Mackay deposits will be assembled with respect to the several problems above enumerated. Because of their interrelation, however, they can not well be taken up in the order of their importance, but rather in the order of cumulative evidence.

PART PLAYED BY MAGMA IN SUPPLYING MATERIAL.

Absence of changes in volume during metamorphism.—A striking feature of the Mackay deposits is the definite relation of many of the ore bodies and presumably all of them to blocks of limestone engulfed in the granite porphyry magma. The several miles of contact along the periphery of the batholith, though fairly well prospected, have revealed no valuable deposits, and in only two or three places have contact silicates been found; the ore occurs entirely within the area of the batholith. If, therefore, the ore and lime silicate rock have been formed by the concentration of impurities within the limestone, the concentration has taken place entirely within the boundary of engulfed blocks. Some of these blocks have been completely transformed into lime silicates and metallic minerals. The approximate composition of the blocks at present and of the original limestone being known, it is therefore possible to compute, roughly to be sure, the volume changes which must have taken place if these minerals are due to a concentration of impurities already in the limestone.

Four analyses of the unaltered blue limestone are available, one by Prof. Kemp and three by W. C. Wheeler, of the United States Geological Survey.

Partial analyses of unaltered limestone from the Alberta level of the Empire mine.

	1	2	3	4[a]
SiO_2	3.92	1.67	2.84	14.77
Al_2O_3	.72	.30	.18	} 3.68
Fe_2O_3	.04	.16	.13	
FeO	.26	.08	.09	......
MgO	12.72	.48	1.03	4.23
CaO	42.14	53.71	54.14	40.62
CO_2	38.98	41.89	41.28	36.58
Loss on ignition, less CO_2	.47	.49	.41	......
	99.25	98.78	100.10	99.88
Specific gravity (lump)	2.810	2.728	2.749	......
Specific gravity (powder)	2.816	2.729	2.749	......

[a] Analysis from paper by Kemp and Gunther (op. cit., p. 276). Partly recalculated to show separately CaO, MgO, and CO_2.

1. From first bend in Alberta tunnel.
2. From a point between first and second laterals in No. 3 crosscut, Alberta tunnel.
3. From No. 4 crosscut near first right lateral, Alberta tunnel.
4. From Alberta tunnel 50 feet from portal.

The analyses show a considerable range in the composition of the limestone, but as the material represents stratigraphic horizons perhaps 200 feet apart the accordance in composition would seem to be fully as noteworthy as the variation. The alumina and iron are uniformly low, and in only one analysis is the silica high. The analyses, therefore, are adequate for purposes of emphasizing the order of concentration necessary if we assume that the silica, iron, and alumina of the silicate rock represent merely a concentration of elements already in the limestone. In order to derive the silica of the massive garnet rock (No. 7 in table, p. 59) from the limestone represented by analysis No. 2, there must be a decrease in volume of about 95 per cent; to derive it from the limestone represented by analysis No. 4, which is exceptionally high in silica, a decrease of about 60 per cent. In order to concentrate alumina and iron, the two other significant elements, a concentration of more than 90 per cent is required for each of the three limestones in which alumina and iron have been separately determined. From these figures, only presented to emphasize an order of magnitude, it is safe to conclude that unless the calcium-silicate rock represents something more than a concentration of material in the limestone, a minimum decrease in volume of 60 to 80 per cent must have taken place; that is, the calcium-silicate rock occupies only 20 to 40 per cent of the space occupied by the original limestone inclusion. As has been emphasized (p. 60), however, the garnetization took place after the solidification and fracturing of the granite porphyry which completely surrounds the limestone blocks. If there had been extensive changes in volume one or both of these rigid rocks should bear record of it. A decrease in volume of 60 to 80 per cent can not be accounted for by the small differences in porosity between the limestone and silicate rock shown in the table below nor by fractures, because these are rare, nor by any supposition postulating open spaces, large or small.

Porosity of principal rock types in the Mackay deposits.

Rock.	Locality.	Specific gravity.		Porosity.
		Lumps.	Powder.	
Limestone [a]	First bend, Alberta tunnel	2.798	2.806	0.012
Limestone [b]	No. 3 crosscut, Alberta tunnel	2.728	2.729	.001
Marble [b]	No. 1 crosscut, Alberta tunnel	2.704	2.720	.016
Wollastonite rock [b]	Cave tunnel, Champion group	2.786	2.805	.019
Garnet-calcite rock [a]	Prospect 1,500 feet northwest of Copper Bullion tunnel.	3.359	3.369	.010
Garnet rock [a]	Alberta tunnel near mouth No. 5 crosscut	3.647	3.697	.050
Fresh granite porphyry [a]	Near end of Alberta tunnel	2.621	2.658	.037

[a] Determined by George Steiger. [b] Determined by W. C. Wheeler.

The joints in the granite porphyry along the periphery of the included blocks of limestone are accompanied by little or no gouge, such as would be expected if they had been surfaces of sufficient readjustment to account for a shrinkage of 60 to 80 per cent in the volume of the inclosed block. In cooling, the magma probably closed in to some extent on the included limestone, but the argument loses any weight which it might otherwise have because the garnetization is clearly subsequent to the solidification and fracturing of the igneous rock. Furthermore, the lime silicate rock in places retains the bedding of the original limestone and elsewhere cuts as veins across bedded marble.

Source of material.—As the physical relations of the granite porphyry to the calcium-silicate rock inclosed within it preclude the possibility of extensive changes in volume within the engulfed limestone blocks during their garnetization, it follows that the great excess of silica, alumina, and iron in the lime silicate rock over that in the limestone must have been introduced. Possible sources seem to be but three: (1) Meteoric waters, which leached the material from the sedimentary rocks; (2) thermal waters, of whatever source, which leached the material from the solidified igneous rock; and (3) magmatic emanations from deeper and unconsolidated portions of the magma or from the source of the magma.

If, according to the first hypothesis, the material is derived from the surrounding sedimentary rocks it appears impossible to account for the absence of metamorphism along the periphery of the intrusion. Adjacent to the ore bodies on the east border of the batholith the extensively jointed limestone dips toward the igneous contact, affording ideal conditions for meteoric waters to gather impurities from the stratified rocks during their descent and to deposit them during ascent along the less fractured granite porphyry. Deposits in such situations, however, are notably absent. On the other hand, they occur as isolated bunches well within the batholith, where such meteoric circulation certainly would not attain its maximum development, if indeed any water could enter the igneous rock while it was sufficiently hot to afford the heat requisite for metamorphism.

If, under the second hypothesis, the solidified and jointed granite porphyry were the source of the foreign material it would seem that the porphyry should show some evidence of material having been leached from it. The ferromagnesian minerals, which contain most of the iron, the element so abundantly added to the contact rock, should show some evidence of leaching, one of the changes to be expected being the transformation of biotite into muscovite. It is particularly noticeable, however, that the igneous rock, away from the immediate contact with secondary silicates and below the zone of surface weathering, is absolutely fresh. Even the products of hydrothermal metamorphism, so abundant in many contact-metamorphic deposits, are almost entirely lacking here. Because of these features the second hypothesis, which postulates leaching of the adjacent porphyry, does not appear worthy of further consideration.

The remaining hypothesis postulates that the silica, alumina, and iron represent emanations from unconsolidated portions of the magma or from the source of the magma. This view has received much support in recent years, especially from Lindgren, Kemp, Spurr, Goldschmidt, and others, but has been strongly opposed as the dominant process by Leith, Barrell, and recently by Uglow. In the Mackay deposits large blocks of limestone, completely surrounded by the igneous rock, were transformed into garnet rock after the solidification and extensive fracturing of the intrusion. There is abundant evidence of essentially constant volume during metamorphism; hence there must have been a vigorous transfer of material to account for the wide difference in composition between the original and the derived rocks. In order to derive 1 cubic meter of the garnet rock from an equal volume of the limestone it is necessary to remove 259 kilograms of CaO and 1,100 of CO_2, and to introduce 314 kilograms of Al_2O_3, 511 of Fe_2O_3, and 1,269 of SiO_2. It is shown above that neither the limestone nor the granite porphyry adjacent to the ore bodies can reasonably be assumed to have supplied the excess material of the silicate rock. This conclusion is based on direct observations and easily interpreted physical relations. So far as it is absolute, and so far as the three possible sources of material are all inclusive, the further conclusion that deeper portions of the magma supplied the material is justified.

Solutions of magmatic origin.—Until very recently reasoning of the general nature outlined above, and the broad observation that in the numerous contact deposits which have been studied and in the diverse relations of individual deposits the only common factor is the proximity of the igneous rock, have been the most reliable supports for the belief that magmatic solutions supply much of the material for contact deposits. Other direct observations, such as hydrous minerals and occluded carbon dioxide and water in igneous rocks, the gradation from igneous rocks to pegmatites and on into metal-bearing veins, and many others perhaps less convincing, have also supported the belief that many ore deposits are the products of solutions of magmatic origin. Recently this belief, firmly held by most investigators but doubted by some, has received strong support from the remarkably fruitful researches at the crater of Kilauea.[1] Gases collected directly from the molten lava contained 300 cubic centimeters of water in a total estimated volume of 1,000 liters of gas. This direct observation that some magmas do contain large amounts of water makes far more rigorous the deductions based on well-known field and laboratory evidence, for if one magma affords water the assumption that another has afforded water is abundantly warranted if supported by evi-

[1] Day, A. L., and Shepherd, E. S., Water and the magmatic gases: Washington Acad. Sci. Jour., vol. 3, pp. 457-463, 1913.

dence in the field. In the abstract, then, the student of ore deposits has two equally available sources of solutions and it remains for him to decide for each district which source is most probable in the light of local evidence. In the contact-metamorphic deposits the alternative that the waters are meteoric implies, because of the transformations accomplished, that they were highly heated and, because of their relation to igneous contacts, that the intrusion supplied the heat. In the deposits at Mackay, therefore, it remains to assemble the evidence and see to which source of solutions it points.

Features to be explained.—The features of these deposits which have a bearing on the source of the metamorphosing solutions are: (1) The influence of joints and faults in the porphyry in directing the solutions; (2) the general fresh condition of the granite porphyry; (3) the garnetization of the igneous rock; (4) the scarcity of lime silicates and the essential absence of ore even in the most favorable situations along the periphery of the batholith; (5) the relation of the garnet rock and the ore bodies to engulfed blocks of limestone; and (6) the vigorous transfer of material recorded in the transformation of comparatively pure limestone into massive garnet rock.

The bearing of each feature on the source of the solutions will be considered separately.

(1) The controlling influence of joints in directing the metamorphosing solutions is proved by the relations in many parts of the deposits. Both the igneous rock and the limestone were jointed and faulted before the metamorphism took place. It is obvious therefore that if the solutions emanated from the unsolidified magma they did not come from that part immediately adjacent to the shoots of ore and garnet. The nearly vertical elongation and arborescent form of the shoots also indicates that the solutions did not come from the side but rather that their movement was dominated by a vertical component.

(2) The general fresh condition of the granite porphyry away from the immediate vicinity of the limestone inclusions appears equally explainable whether the solutions emanated from deeper portions of the batholith or were of the meteoric circulation. It may indicate either that they were confined to trunk channels and the rock closely adjacent, or that they were incapable of attacking any of the constituents of the igneous rock until after coming in contact with limestone. The localization of the deposits in the vicinity of included blocks of limestone, and near only certain of these blocks, implies that both factors were determinative, but they would appear to be equally operative, whether the solutions be considered of magnetic or of meteoric origin.

(3) The garnetization of the igneous rock implies solutions heavily charged with lime as well as with alumina and iron, and it may appear at first thought that this preponderance of lime favors solutions which entered through the surrounding limestone. On the other hand, every observed occurrence of garnet rock derived from porphyry is closely associated with similar rock derived from limestone. It is believed, therefore, that garnetization of the porphyry took place only where near-by limestone afforded the requisite lime. Meteoric solutions passing from without through the limestone into the solidified and jointed igneous rock would certainly have been charged with lime when they reached the igneous mass, and thus the garnetization of the porphyry would not have been dependent on included blocks of limestone. Furthermore, if the waters came from without the batholith, and they were capable of garnetizing the porphyry, they would have done so along its periphery instead of only at considerable distances (locally 2,000 feet) within the igneous mass. It is believed, therefore, that the localized garnetization of the porphyry at once strongly supports the belief that the solutions were of magmatic origin and refutes the alternative that they were of the meteoric circulation.

(4) Similarly it seems impossible to account for the absence of ore and lime silicates derived from limestone in structurally favorable situations along the periphery of the contact if we conceive the depositing solutions to have migrated toward the magma and there to have acquired heat and on ascent deposited material from solution. On this general supposition the solutions may have traveled upward along the contact or more likely upward and outward along courses determined by the combined effect of fracture zones and heated surfaces. Deposits of noteworthy importance thus situated, however, have not been found, and it seems entirely unreasonable to assume that external solutions should pass by the main con-

tact and only become effective as metamorphosing agents when engulfed blocks of limestone are reached. Particularly is it unreasonable because the metamorphism took place after the solidification of the igneous rock and after the magma became partly solidified the rocks along its periphery must have passed through all the degrees of falling temperature experienced by the included blocks. On the other hand, if the solutions emanated from the interior of the intrusion they would deposit at the point where they first came in contact with material with which they could react—in this area with the inclosed blocks of limestone. It is believed, therefore, that the position of the ore bodies and the shoots of lime silicate derived from limestone strongly indicates that the emanations came from the magma.

(5) The relation of the shoots of lime silicate and of the ore shoots to blocks of limestone and their absence in places distant from such blocks seem to indicate that the presence of limestone was an essential factor in the metamorphism. If it was thus necessary to derive vast amounts of lime from limestone it is obvious that the metamorphosing solutions were not saturated with calcium oxide or its compounds nor did they contain sufficient amounts of these materials to become saturated except at places where limestone was available and the lime utilized. This dearth of lime is readily accounted for if the solutions emanated from the magma, for calcium compounds are exceedingly rare in volcanic sublimates and their presence in magmatic waters is doubtful. If, on the other hand, meteoric waters descended along structure planes to the hot igneous contact it would appear indubitable that a vast load of lime, as bicarbonate or otherwise, should be accumulated and should be available for garnetization in the absence of limestone. In the abstract, however, the possibility remains that meteoric waters could have been delivered to the lower part of the contact and not to the upper and that there garnetization has taken place. This possibility was entertained in the field but finds no support in the structural relations of the surrounding limestone to the batholith nor in the character of the beds which underlie the limestone. The extent of erosion since intrusion is not known, but the granite now crops out through a vertical range of nearly 2,500 feet and it is probably reasonable to assume a cover of at least 1,000 feet. In the absence of faults which would cut off the flow through beds that dip toward the contact, it must be concluded that fully as much water would have been delivered to that part of the contact now exposed as to any deeper part. Indeed, the many observations in deep mines indicate that much more meteoric water would be delivered at levels above 3,500 feet than at levels below that depth. This does not mean necessarily that meteoric waters would not reach to lower depths but that their circulation would be more active at higher levels. It is considered unreasonable, therefore, to assume that larger quantities of solutions of meteoric origin could have been delivered to the intrusion at greater depth than within the 2,500-foot zone now exposed. Of the two possibilities, therefore, that the solutions emanated from the magma, or that they descended along structural planes and invaded the hot igneous rock from the surrounding limestone, the dependence of the solutions on the included limestone blocks for lime strongly favors the alternative that they emanated from the batholith.

(6) The vigorous transfer of material involved in the transformation of comparatively pure limestone into massive garnet rock (see p. 72) emphasizes still further the anomalous absence of lime silicates along the periphery of the batholith, if it be assumed that the solutions invaded the magma from without. If, on the other hand, they emanated from deeper portions of the intrusion there is no reason to believe that they escaped laterally, for the form of the ore shoots indicates that their paths approached closely to the vertical. At the point of escape from the igneous rock into the overlying limestone garnet probably formed but has been removed by erosion. At the intersection of the Alberta fault with the limestone the development of garnet seems also likely, and it has been developed locally. (See fig. 3, p. 46.) The garnet vein on White Knob extends vertically across overlying beds of marble. The absence of even a discontinuous peripheral zone of lime silicates, therefore, indicates that solutions capable of such intense metasomatism did not transgress the igneous rock from the surrounding limestone. This indication is vastly strengthened because there is absolutely no reason, structural or otherwise, for believing that meteoric solutions did not

tend just as strongly, if not more so, to approach the igneous rock at the levels of the present accidental surface as at greater depths.

Summary.—In preceding paragraphs the bearing of the six prominent features of the Mackay deposits on the source of the metamorphosing solutions has been considered. In this consideration very little of theory has been introduced. An effort has been made in the consideration of each feature to utilize broad physical relations involving only a short step between observation and interpretation. Four of the six major features of the deposits which must be accounted for (3, 4, 5, and 6) may be readily explained on the assumption that the solutions came from deeper portions of the magma and refute the alternative view that they entered the igneous rock from the surrounding limestone. The two other prominent features (1 and 2) may be interpreted perhaps equally well on either assumption. Certainly neither favors meteoric circulation over magmatic emanations.

In conclusion, therefore, the evidence of the Mackay deposits appears to be overwhelmingly in favor of emanations from deeper portions of the batholith. The alternative that the metamorphism was caused by a meteoric circulation stimulated by the intrusion is not only improbable but is believed to be altogether untenable in view of the several features that must be accounted for.

SOLUTIONS A DIFFERENTIATE FROM THE GRANITE PORPHYRY MAGMA.

From the preceding discussion it is concluded: (1) That the garnetization at Mackay took place after the solidification and jointing of at least the outer few hundred feet of the batholith; (2) that the marmarization probably occurred in part at the time of intrusion; (3) that the metamorphism was not effected by a succession of distinctly different solutions but rather by a single solution that underwent gradual change as the process proceeded, so that in general the metallic minerals formed later than the silicate minerals; (4) that the great amount of iron, silica, and alumina represent additions from the magma and can not be accounted for either by assuming a concentration of impurities in the original limestone inclusions or by leaching from the external limestone.

The writer's conception of the succession of events which brought about the observed relations is as follows: As the intrusion came to rest emanations consisting largely of water gas escaped into the overlying limestone, causing extensive marmarization, as on White Knob. This effect was essentially a rearrangement of material already present in the limestone and certainly did not result in important contributions. The process seems to have been succeeded by a period of essential quiescence, during which marginal solidification of the magma was accomplished. This solidified zone was fractured. Then solutions capable of energetic metasomatic replacement escaped through the fractures.

The physical relations of the deposits lend strong support to the conception as outlined thus far. Further, we may conceive (1) a parent magma reservoir whence sprang at different times both the granite porphyry magma and the metamorphosing solutions, or (2) that the solutions which escaped during metamorphism were distributed rather uniformly through the granite porphyry magma at the time it came to rest and that their expulsion accompanied its crystallization. Of these two hypotheses the second is favored by local evidence. If the differentiation had taken place in a magma reservoir remote from the place now occupied by the granite porphyry it seems strange that material of the second advance should follow paths wholly within the material first injected. It seems rather that solutions advancing subsequent to this injection would have followed the joints of the limestone adjacent to the granite porphyry. Furthermore, if the metamorphism is not closely dependent on the local igneous mass it is difficult to account for the unaltered aplite dikes which traverse garnet areas. The metamorphism certainly antedates the aplites or is a phase of their injection, for in no place are they altered as is other igneous rock similarly situated. Indeed they are believed to be younger than the metamorphism, for if they represent channels along which traveled the iron-laden solutions which supplied material for the garnet rock they should contain iron compounds in addition to feldspar and quartz at places where they traverse garnet-magnetite rock. As aplites are generally considered to be differentiates from the lower parts of the igneous mass that incloses them, it seems necessary to believe that the ore solutions were operative before the complete crystallization of the local mass of granite porphyry. If the ore solutions came from a deep-seated parent magma, therefore, they advanced into the granite porphyry through a part of it which was still in a molten condition, and the problem of their further expulsion from the molten interior into the fractured shell would be the same as if they had always been a part of the magma. It would seem, therefore, that the second hypothesis alone need be considered, and it remains to form some conception as to how the elements of the metamorphosing solutions may have been concentrated and expelled after the crystallization and fracturing of an outer shell.

In elaboration of this conception the cooling of the peripheral zone of the magma may be conceived as effecting a barrier to the normal escape of solutions. As the cooling progressed inward these solutions may well have been concentrated inward and downward by fractional crystallization. It is probable that such concentration could not continue indefinitely, but there seems to be no reason why it should not persist during the formation of a shell several hundred feet thick. Fractures traversing the outer shell would afford avenues of escape for the solutions which, because of long-continued concentration, may well be considered capable of the deposition of the large quantities of material recorded by the lime silicate rock.

This general conception fits the conditions at Mackay better than any other which has been considered, as it is thus possible to account for a lapse of time between a period of marmarization at the time of intrusion and one of garnetization at a subsequent time. The chief difficulty is to conceive a rational mechanism for the inward concentration of volatile constituents, which normally would tend to escape outward. It is probably safe to assume that crystallization of the magma begins at the periphery and progresses inward, a transition zone of partly crystallized material always separating the solid shell from the liquid core. How wide this transition zone would be is entirely speculative. An inward concentration of the material that is not incorporated in the final rock, however, requires that its elimination must take place from this zone of incomplete crystallization. Here the concentration of such excess material as water vapor would be greatly raised because of the decrease in the total volume of liquid components incident to the growth of crystals. Diffusion from this zone of higher concentration would tend to establish equilibrium throughout the mass, thereby raising in it the concentration of materials comprising the residual fluid magma, unless fractures or porosity in the solidified shell allowed them to escape outward. It is a matter of observation, however, that the outward escape was along fractures; in the Alberta workings along a considerable fault, implying a shell at least a few hundred feet thick. Further, the solutions causing garnetization were more highly concentrated with respect to iron, silica, and alumina than those expelled at the time of intrusion, which only caused marmarization. It is suggested, therefore, that residual material found a way into unsolidified portions of the magma. Its transfer may have been by diffusion, although this seems to involve serious difficulties, because of the extreme slowness of the movement, as pointed out by Becker.[1] Harker, however, believes that "diffusion proceeds freely in a cooling rock magma long after the increasing viscosity has rendered bodily movement impossible."[2] It is possible that a combination of this idea and a conception of differentiation favored by Pirsson[3] in his discussion of the Highwood laccoliths may meet the requirements of the problem. Pirsson's explanation of differentiation within a laccolith postulates "a combination of convection currents and the tendency to crystallize first at the outer walls." He believes that the heat set free by crystallization and "the resulting concentration of the chemically combined water vapor in the magma * * * would tend to counteract the increasing viscosity due to cooling." The convection currents would be upward in the center and downward along the sides. Thus crystallization would proceed most rapidly well down on the margins of the magma, and as it proceeded "the edges of the outer crust would rise more and more toward the top, finally spreading over it, and as a result the crust should be thinner on the top than

[1] Becker, G. F., Computing diffusion: Am. Jour. Sci., 4th ser., vol. 3, pp. 280-286, 1897.

[2] Harker, Alfred, The natural history of igneous rocks, p. 319, 1909.

[3] Pirsson, L. V., Petrography and geology of the igneous rocks of the Highwood Mountains, Mont.: U. S. Geol. Survey Bull. 237, pp. 187-190, 1905.

elsewhere." It would seem to the writer, however that diffusion, even though a slow process and one perhaps not effective through considerable distances, must have been the means of delivering the material to the convection currents. Viscosity in the outer part of the transition zone between material wholly solid and that wholly liquid certainly would be so great that the material close to the solid mass would not be involved in a convection movement. The conception that during crystallization the crust was thinner on top is favored (1) by the greater metamorphism observed on top of the intrusion than along its sides, and (2) by the greater thickness of fine-grained porphyry on the sides of the batholith than on the top of it.

If through some such conception as outlined above it is possible to account for concentration in the fluid magma it is easy to picture the expulsion of the residual fluid material through fractures developed in the outer shell, and thus to account for a lapse of time between marmarization at the time of intrusion and metasomatism subsequently. When in the central part of the magma crystals have become so numerous that they may be likened to a sponge saturated with steam under great pressure, fractures in the inclosing crust would relieve the pressure and readily allow the escape of the concentrated residual material. The volatile residuum thus escaping by expansion would be augmented by fluid material squeezed out by a crowding together of the crystals because of reduced resistance to external pressure.[1] The aplite dikes may be an end product of this later process.

The conception may be of somewhat general application. If the concentration is very high garnetization will accompany the rise of the magma into regions of less pressure or may even progress well in advance of the intrusion; if it is low, inward concentration will be necessary before garnetization can take place. Several so-called periods or waves of metamorphism may merely mean fracturing, sealing of the fractures, and refracturing. The fractures may be sealed by pegmatitic or aplitic material or the progressive thickening of the shell may form a barrier across their inner ends.

The above conception, except the bearing of the concentration suggested in the last paragraph, is merely an adaptation to the occurrence at Mackay of different conceptions already expressed in the literature. The following references will suffice to illustrate:

Vogt, J. H. L., Problems in the geology of ore deposits, Genesis of ore deposits, pp. 641–658, 1901.

Irving, J. D., Ore deposits of the Ouray district, Colo.: U. S. Geol. Survey Bull. 260, pp. 73–75, 1905.

Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: U. S. Geol. Survey Prof. Paper 43, pp. 218–223, 1905.

Kemp, J. F., The copper deposits at San Jose, Tamaulipas, Mexico: Am. Inst. Min. Eng. Trans., vol. 36, pp. 178–203, 1905.

Spencer, A. C., The magmatic origin of vein-forming waters in southeastern Alaska: Am. Inst. Min. Eng. Trans., vol. 36, pp. 366–367, 1905.

Spurr, J. E., A theory of ore deposition: Econ. Geology, vol. 2, pp. 781–795, 1907.

Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Coeur d'Alene district, Idaho: U. S. Geol. Survey Prof. Paper 62, pp. 134–140, 1908.

Iddings, J. P., Igneous rocks, vol. 1, pp. 260–276, 1909.

Knopf, Adolph, Some features of the Alaska tin deposits: Econ. Geology, vol. 4, pp. 221–223, 1909.

Emmons, S. F., Cananea mining district of Sonora, Mexico: Econ. Geology, vol. 4, pp. 334–335, 1910.

Goldschmidt, V. M., Die Kontaktmetamorphose im Kristianiagebiet, p. 108, 1911.

Spurr, J. E., A theory of ore deposition: Econ. Geology, vol. 7, pp. 485–486, 1912.

Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, pp. 133–135, 1913.

APPLICATION OF PRECEDING CONCEPTION OF GENESIS.

The conception of genesis of the ores outlined above may be of somewhat general application, for its keynote is the concentration of the metamorphosing constituents in the magma. It is believed to embrace three general forms: (1) If the concentration of the metamorphosing constituents in the magma is very high the development of secondary silicates may proceed well in advance of the forward-moving magma; (2) if their concentration is somewhat lower garnetization will begin as soon as the magma has risen to regions of sufficiently reduced pressure, perhaps not until it has come to rest and started to congeal; (3) if the concentration of the metamorphosing constituents in the magma is very low, concentration by crystallization, beginning at the surface of the molten mass and progressing inward, will be necessary before the solutions can escape.

Many well-known contact deposits illustrate metamorphism at the time of intrusion, and several point unquestionably to metamorphism after the solidification of the outer part of the

[1] Harker, Alfred, The natural history of igneous rocks, p. 323, 1909.

magma. No satisfactory example of metamorphism as an advance wave of intrusion, however, has been recorded; but perhaps this is to be expected, as metamorphism at that time would, according to the conception, probably be followed by the escape of solutions continuously until the margin of the magma solidified and again at a later time when fractures developed through an outer solid wall. Thus the earlier products of metamorphism would be difficult to disentangle from those later developed. It is possible that this first variety may be illustrated by the Haliburton and Bancroft areas in Canada, where some of the innumerable inclusions of sedimentary rocks in the granite appear to have been contact metamorphosed by the magma before they were engulfed in it.[1]

Illustrations of metamorphism at about the time the magma comes to rest are more numerous, and some students of wide experience believe that at this time most of the metamorphism is accomplished. In the Clifton-Morenci deposits Lindgren distinguishes clearly between the contact metamorphisms by solutions "which emanated from the magma at the moment of intrusion" and those which "after the consolidation of the porphyry" and its extensive fissuring "flowed through these fissures."[2] The copper deposits at San Jose, Tamaulipas, Mexico, which occur in a zone of metamorphosed Cretaceous (?) limestone, were caused by a mass of diorite porphyry[3] that comes in sharp contact with garnet rock of limestone derivation and in no place is itself garnetized, although pyrite occurs through it and along tiny fractures adjacent to the contact zones. It would seem that this deposit also represents the two stages described by Lindgren in his Clifton-Morenci paper. In most of the contact deposits of New Mexico the intrusive rock—

> has remained entirely unaltered and the contacts are perfectly sharp. At a few places the intrusive has been converted into epidote for a short distance from the contact, but as fissure veins and attendant alteration of the country rock constantly accompany the intrusives as a development later than contact metamorphism it is probable that the observed mineralization of the intrusive belongs to this class of phenomena.[4]

The last part of the quotation gives support to the conception that the concentration of the metamorphosing constituents in the magma determines the stage at which they escape, because if they escape at the time the magma comes to rest, they should also escape subsequently, which seems to have happened at Clifton-Morenci, at San Jose, and in the New Mexico deposits. The same is true of the Marysville[5] and Christiania[6] deposits, where metamorphism both at the time of intrusion and subsequently are recognized.

Examples of metamorphism after the consolidation of the magma (the third form mentioned above) stand out more definitely, particularly if only those be included in which endomorphism is a pronounced effect. Indeed the evidence in such examples that the solutions escaped from deeper portions of the magma is so convincing that Spurr was led to state from his study of Dolores and Velardeña that "the common conception that contact metamorphism, or the formation of lime silicates, is due to the effect of solutions pressed out and expelled from the immediately adjacent intrusive rock into the wall rock at the time of its consolidation is regarded as an elementary one, not corresponding to the facts." In both occurrences the record indicates that "contact metamorphism began after the intrusive rock had become consolidated, so as to permit of extensive fracture, though under great pressure; that along these fractures the metamorphosing solutions rose from below and attacked and replaced intruded and intrusive rock alike."[7] At Concepcion del Oro the granodiorite is garnetized adjacent to the Cretaceous rocks which it traverses, and Bergeat concludes that it had solidified before the metamorphism took place.[8] The White Horse deposits in the Yukon Territory also illustrate metamorphism after the solidification of at least the outer part of the granite. Most of the ore occurs in the adjacent limestone, but appreciable amounts occur in the granite. Large quantities of andradite, augite, and green epidote replace the granite

[1] Adams, F. D., and Barlow, A. E., Geology of the Haliburton and Bancroft areas: Canada Geol. Survey Mem. 6, pp. 97, 164, 225, 1910.

[2] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, p. 176, 1905.

[3] Kemp, J. F., The copper deposits at San Jose, Tamaulipas, Mexico: Am. Inst. Min. Eng. Trans., vol. 36, pp. 178-203, 1905.

[4] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 56, 1910.

[5] Barrell, Joseph, Geology of the Marysville mining district, Mont.: U. S. Geol. Survey Prof. Paper 57, p. 146, 1907.

[6] Goldschmidt, V. M., Die Kontaktmetamorphose im Kristianiagebiet, p. 108, 1911.

[7] Spurr, J. E., Theory of ore deposition: Econ. Geology, vol. 7, p. 485, 1912.

[8] Bergeat, A., Der Granodiorit von Concepcion del Oro im Staate Zacatecas (Mexiko) und seine Kontaktbildungen: Neues Jahrb., Beilage Band 28, pp. 421-573, 1909.

in places [1] and warrant the conclusion that the metamorphosing solutions rose after the cooling of at least the outer part of the magma. At Silverbell, Ariz., endomorphism has unquestionably taken place, but the products of it are not abundant,[2] and the occurrence perhaps should be placed under the preceding group. The deposit at Mackay is a striking representative of this group, nearly all of the garnetization having occurred after the consolidation and fracturing of an outer shell several hundred feet thick. Butler, as a result of his studies at San Francisco, Utah, suggests that there the solutions escaped after the consolidation of the margin of the magma, because "the great extent of mineralization at certain points [along the contact], however, suggests that the solutions given off by the crystallizing magma were collected in channels and entered the limestone at these points rather than uniformly along the entire contact zone,"[3] as would be expected if the metamorphism had taken place before the solidification and fracturing of an outer magma shell. An application of this argument would place several other deposits in the third group, but it is considered less rigorous than extensive endomorphism, unless it is demonstrated for each deposit that the rocks in juxtaposition at points where there has been no contact effect are the same in composition and structure as those at points where metamorphism is intense. By a course of reasoning analogous to this Irving reached the conclusion that at Ouray, Colo., the metamorphosing solutions "reached the limestone by means of fissures" in the monzonite porphyry.[4]

This review of the more important literature indicates that deposits have been described which illustrate each of the varieties of metamorphism resulting from the conception that the degree of concentration of the metamorphosing constituents in the magma determines whether they begin to escape (1) as an advance wave of intrusion, (2) at the moment of intrusion, or (3) after the consolidation and fracturing of a magma shell. If the initial concentration is so high that they escape during the first stage, falling temperature and pressure may be expected to perpetuate the escape throughout the second stage. This stage and the third, however, are conceived to be separated by a period during which the unfractured magma crust forms a comparatively impervious barrier to the escape of volatile constituents. The fact that in some places products of contact metamorphism and in others those of hydrothermal metamorphism represent the third stage is not considered inimical to the conception, as equally pronounced variations in dike sequence have long been recognized; doubtless the two sets of phenomena involve similar physicochemical laws.

[1] McConnell, R. G., The White Horse copper belt, Yukon Territory: Canada Geol. Survey, pp. 25 et. seq., 1909.

[2] Stewart, C. A., The geology and ore deposits of the Silverbell mining district, Ariz.: Am. Inst. Min. Eng. Trans., vol. 43, pp. 240–290, 1913.

[3] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 90, 1913.

[4] Irving, J. D., Ore deposits of the Ouray district, Colo.: U. S. Geol. Survey Bull. 260, pp. 73–75, 1905.

LEAD DEPOSITS.

Lead deposits occur in the contact zones of the Alder Creek district, and although not of proved commercial value, they must be given a place in a systematic treatment of the contact deposits. At the time of the examination none of the deposits of lead were being worked and nearly all of the tunnels and shafts exploring them were inaccessible. Lead occurs in pockets along the east contact of the large limestone inclusion (Easlie group) near the northern border of the area shown on Plate VII (in pocket). The limestone here is marmarized, and thin sections of it reveal a minor development of wollastonite and actinolite. On the Horseshoe group also a few small lenses of lead ore have been found in the granite porphyry. In the Grand Prize shaft occurs a tabular lead deposit which is more properly included under the vein deposits but is mentioned here because it is entirely inclosed in the granite porphyry within 1,200 feet of an area of intensely contact-metamorphosed rock. The galena here occurs in a siderite gangue. The veins of the Champion group are also near areas of garnet rock, though they are inclosed in limestone. (See p. 101.)

The general occurrence of lead ore in the porphyry is of especial interest because it is distributed as outliers of the area of contact copper deposits. The lead and the copper deposits are certainly of about the same age, and the metals certainly emanated from the same magmatic source. Thus the relations suggest strongly that the lead-bearing solutions wandered farther from the centers of emanation than did those containing copper;

that is, they were deposited under conditions of less temperature and probably also of less pressure. This general relation agrees with the observations of Ward,[1] Spurr,[2] and others cited by Ward.

VEIN DEPOSITS.

CLASSES OF VEINS.

Vein deposits of pre-Oligocene age occur in many parts of the Mackay region, but they have not been extensively developed, and production from them has been small compared with similar deposits elsewhere in east-central Idaho. In general these veins represent tabular replacement deposits along fracture zones and may be classified, according to the principal metal which they contain, as copper veins, lead-silver veins, and tungsten veins. The copper veins include replacements both along fissure zones and along the bedding planes of the inclosing rock. The lead-silver veins occur in limestone, in quartzite, and in granite porphyry. The tungsten veins were discovered after the writer's visit to the region and little is known of them.

COPPER VEINS.

Copper-bearing vein deposits occur in the Clyde district in the west slope of Lemhi Range and in the Skull Canyon district on the east wall of Birch Creek valley in the extreme southeast corner of Lemhi County. The deposits of the Skull Canyon district have had some commercial development, for they have produced $60,000 to $70,000 worth of copper, but those of the Clyde district have produced only a little and are meagerly developed.

In both districts the copper deposits are inclosed in sedimentary rocks and there are no igneous rocks in the vicinity.

SKULL CANYON DEPOSITS.

The principal copper deposits known in Skull Canyon are comprised in the group of eighteen patented claims owned by the Weimer Copper Co. The rock formations here consist of a series of quartzite beds, about 500 feet of which is exposed. These quartzite beds are overlain by thick beds of magnesium limestone, including numerous thin light-gray beds above the lower 500 feet. The thickness of the limestone is not known, but high peaks in the eastern, unvisited part of the district are composed of rocks which from a distance appear to be thin-bedded shales and limestone. No igneous rock either in place or as boulders along the streams was observed in the area.

Ore bodies have been opened on the northeast side of the canyon, where they occur in the magnesian limestone, and on the southeast side, where they are inclosed in the quartzite. The ore bodies in the limestone follow the bedding planes; those in the quartzite occur as veins which cross the beds of the inclosing rock. The veins that follow the bedding crop out about 200 feet above the canyon floor and dip into the hill at a low angle. Where exposed by numerous tunnels and open cuts along several hundred feet of the outcrop, they are composed of a heavily iron-stained, jaspery material which incloses irregular lenses and slabs of limestone and large bunches of hematite. In places the veins split into two or more veins or cross along joints from one bedding plane to another a few feet away. The stopes which have furnished most of the production suggest considerable ore bodies from 18 inches to 6 or 7 feet thick. The ore is well oxidized throughout the present workings, all of which are dry. Malachite and ferruginous chrysocolla are the characteristic ore minerals.

The vein in the quartzite southwest of the canyon was not examined adequately because of a cave near the mouth of the principal tunnel, but it is said to be from 18 inches to 2 feet in average width, although in one place it is 25 feet across. The ore minerals consist of malachite, azurite, chrysocolla, chalcopyrite, and small amounts of bornite, chalcocite, cuprite, copper-pitch ore, and pyrite. Galena, together with anglesite, cerusite, and a little beautifully crystallized wulfenite, occurs in the vein as sparsely scattered bunches from 1 to 5 feet across. (See Pl. XVII, *C*, p. 69.) The common gangue is a dark-brown ferruginous amorphous material containing some copper. Barite is scattered through the ore irregularly as bunches and small crystals conspicuous because of their whiteness. In most places the barite is separated from the chalcopyrite by a band of copper-pitch ore, but in one of the specimens the two minerals are in sharp contact in such

[1] Ward, L., An investigation of the relationships between the ore bodies of the Heemskirk-Comstock-Teehan region and the associated igneous rocks: Australasian Assoc. Adv. Sci. Rept., vol. 13, pp. 148-164, Sydney, 1911.

[2] Spurr, J. E., A theory of ore deposition: Econ. Geology, vol. 7, pp. 485-492, 1912.

a way as to suggest contemporaneous origin. The barite was not seen in any of the completely oxidized ore but is fairly abundant in specimens containing galena and chalcopyrite. All these specimens, however, are partly altered and the mineral relations are such that although the barite is thought to be a primary mineral the determination is not definite.

The wulfenite occurs as thin orange-colored crystals, differently oriented, lining cavities in the galena ore. Associated with it in most places are small clear-white orthorhombic crystals of cerusite and milky-white bunches of barite. The wulfenite, like the cerusite, is clearly a secondary mineral, although the immediate source of the molybdenum which it contains is not known. Very careful tests on the fresh galena by R. C. Wells, of the United States Geological Survey, failed to reveal any molybdenum in the galena from which the cerusite had altered.

BASINGER CANYON DEPOSITS.

In Basinger Canyon, in the Clyde district, auriferous copper ores occur in the Copper Bluff mine along the bedding planes of a thick-bedded blue magnesian limestone, which strikes N. 20° W. and dips 65° NE. The vein is locally as much as 18 inches wide, but in many places it narrows to a mere seam, which continues between the sharply defined walls. Development probably does not exceed 250 feet. The ore as seen on the dump consists of chrysocolla, malachite, and azurite in a quartz gangue.

Replacement phenomena are clearly shown by swells of the ore into the wall rock and by small patches of ore minerals entirely surrounded by wall rock. In general, however, the walls are well defined.

LEAD-SILVER VEINS.

OCCURRENCE.

The lead-silver deposits of the area occur characteristically as tabular replacements along fissure and crushed zones. They occur in the several districts along Lemhi Range and the spur of mountains which borders Birch Creek valley on the east, and in the Antelope, Alder Creek, Copper Basin, and Muldoon districts. The veins of the Dome district have in recent years been the most productive representatives of the lead-silver deposits and are of particular interest because they occur in quartzite that has been extensively replaced by the ore minerals and in most places impregnated with manganese now in the form of oxides. The veins of the Alder Creek district are noteworthy because they occur within the general zone of contact metamorphism, although not within the areas of the most intense activity. In the Antelope district the lead-silver veins occur in the Paleozoic beds near an area of andesite and are included with the older deposits, although possibly they should be considered of late Tertiary age and grouped with the closely similar deposits that occur in the eruptive rocks of the Lava Creek and Era districts.

In the following discussion the lead-silver deposits are grouped as veins in quartzite, in limestone, and in granite porphyry.

LEAD-SILVER VEINS IN QUARTZITE.

DISTRIBUTION.

Lead-silver veins in quartzite occur in the Dome and Copper Basin districts, but only the deposits in the Dome district were accessible for study during the summer of 1912. It is believed, however, from a surface examination that the deposits in the Copper Basin district are distinctly different from those of the other district. The deposits in the Dome district are characterized by disseminated lead in the quartzite and by the introduction into the wall rock of large amounts of some compound that on breaking down gives oxides of manganese and iron. Nothing of this sort was suggested by the tunnel dumps of the Copper Basin mines. The deposits of the two districts are different also in that the ores of the Copper Basin district contain much more silver in proportion to the amount of lead than the ores of the Dome district.

DEPOSITS OF THE DOME DISTRICT.

Occurrence.—The rock formations exposed in the vicinity of the lead-silver deposits of the Dome district are made up predominantly of quartzite, but within the quartzite series is a shale member and above it, well back from the deposits, are massive beds of magnesian limestone. No igneous rocks occur in the vicinity and so far as known the workable deposits occur wholly within the quartzite formations. (See Pl. XVIII.)

A sharp overturned fold along which thrust faulting has occurred traverses the quartzite beds along a course N. 30° W. Several normal faults follow this axis of folding but dip to the northeast, whereas the plane or planes of thrust faulting dip to the southwest. Both types of displacement have thrown older beds on the southwest against younger beds on the northeast. The two types of faults are believed to represent distinct epochs of disturbance, of which the thrust faulting that accompanied the folding took place first. (See p. 115.)

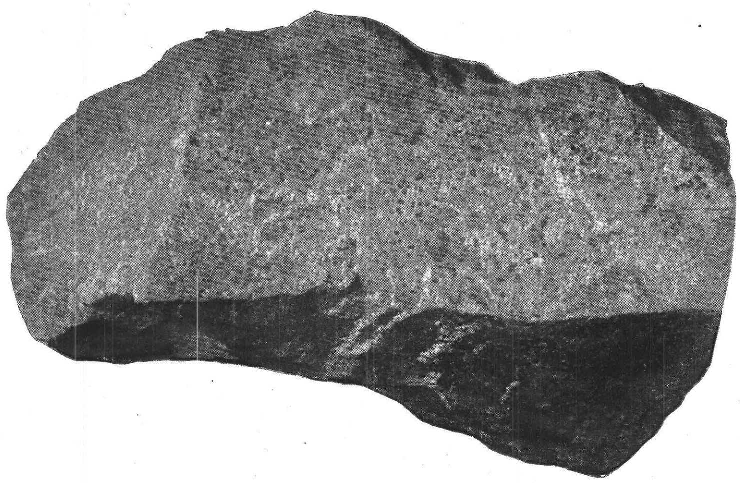
The ore bodies are distributed along the zone of sharpest bending in the overturned fold and along the plane of the thrust fault that resulted from it. The ores in the zone of bending occur as stringers and disseminations in the crushed quartzite and in the plane of the thrust fault as vein deposits. The two types have contributed about equally to the total production, which previous to January, 1914, amounted to 9,650,550 pounds of lead and 36,618 ounces of silver.

Features of the ore.—The ore of the Dome district is of especial interest, because in much of it the ore minerals occur as minute grains disseminated in quartzite. Ore of this variety has a pepper-and-salt appearance (see Pl. XIX, *B*), but the relative amounts of the light and dark grains are very different in different places and locally within distances of a few inches. In most places the ore bodies of this type blend with the inclosing rock by imperceptible gradation through a zone from a few inches to 5 feet wide. Poorly defined bands of fairly pure galena cut in different directions through the disseminated ore and in places coalesce into rather distinct veins composed of thin lenses and stringers of galena and anglesite. Another type of ore in the crushed zone along the fault is composed of quartzite breccia in which galena is the cementing material. (See Pl. XVII, *D*, p. 69.) This ore is a phase of a third type that is found along the plane of the thrust fault where galena occurs as a fissure filling between walls which, although presenting abundant evidence of replacement phenomena, are well defined.

Thin sections of the disseminated ore when studied with the microscope show that the galena replaces the cement and to some extent the quartz grains in a fine-textured quartzite. Some of the unaltered quartzite has a cement composed of lime and silica, but in those beds in which the ore occurs the cement seems to have been entirely siliceous. Specimens of the disseminated ore effervesce slightly in acid and show in thin section a small but rather evenly distributed amount of cerusite on the outer margins of anglesite areas, many of which contain cores of galena. This carbonate, the only one noted in the sections of ore studied, is clearly of secondary origin.

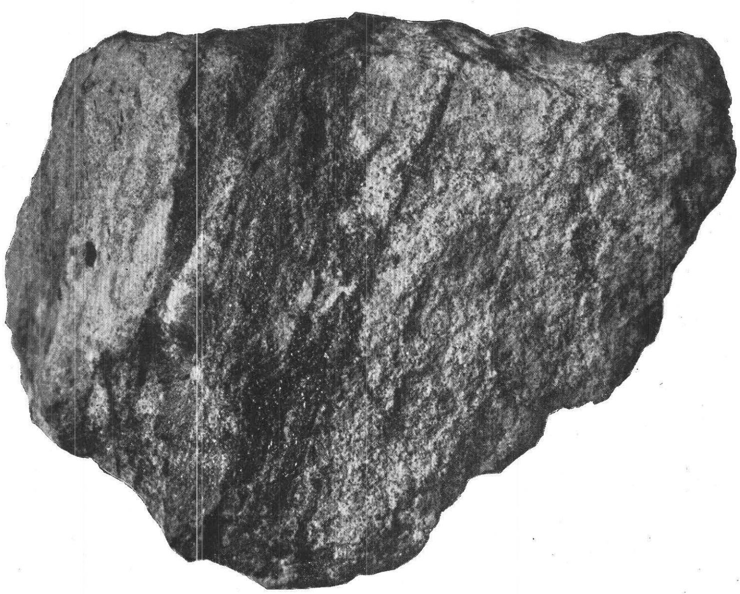
In the disseminated ore anglesite, the sulphate of lead, is by far the most abundant metalliferous mineral. Sections of it usually show irregular cores of the galena from which it was formed. The alteration of galena to anglesite necessitates an increase in volume of approximately 52 per cent (computed on the basis of average specific gravities), and the change from galena to cerusite an increase of only 28 per cent. In these deposits anglesite occurs so commonly as a band between a core of galena and a rim of cerusite that it is probably safe to assume that here at least it represents an intermediate stage in the alteration of lead sulphide to lead carbonate. The change in volume in the alteration of any given grain of galena to cerusite is therefore first an increase of 52 per cent in volume and then a decrease of 24 per cent, the net result when carbonization is complete being an increase of 28 per cent. The maximum possible increase of 52 per cent is probably never realized, for it is likely that cerusite begins to form before a given grain of galena is completely changed to anglesite. There is, however, a cycle of change in volume in the direction stated. The writer believes that this increase in volume followed by a marked decrease during alteration accounts for the "sand carbonate" ores of many mines, so named because of the loose assemblage of the cerusite grains. In these deposits the changes in volume which accompany the alteration of galena to anglesite and of this in part to cerusite appear to have had a decided influence on the coherency of the inclosing rock and to account for the loose sandy condition of the plumbiferous quartzite, as opposed to its closeness and fine texture where not metallized.

Alteration of the wall rock.—The alteration of the wall rock of these deposits is also of particular interest. Oxides of iron and manganese are abundantly developed in the wall rock for several feet away from the ore bodies. They



A. MANGANESE OXIDE (SPECKS) IMPREGNATING QUARTZITE WALL ROCK, DOME DISTRICT, IDAHO.

Natural size.



B. GALENA (BLACK SPECKS) DISSEMINATED IN CAMBRIAN QUARTZITE, DOME DISTRICT, IDAHO.

Natural size.

are most abundant next to the ore and where observed grade out to the unaltered quartzite within a distance of 10 to 50 feet. The altered wall rock is striking in appearance (see Pl. XIX, *A*), a bright yellow groundmass of iron oxide being thickly studded with small specks of dendritic manganese. The oxides occur not only along the innumerable fracture surfaces but throughout the rock as interstitial fillings between the quartz grains. Calcite in most places accompanies the metallic oxides. Perhaps its most common situation is along the cleavage cracks, but in places it occurs also interstitially between the quartz grains. In many parts of the hand specimens where no carbonate is visible, even with the aid of a hand lens, a drop of acid causes vigorous effervescence, indicating that the carbonate is present but is concealed by the oxides.

The occurrence of these oxides and calcite in the wall rock is in every particular comparable to the occurrence of the lead minerals in the disseminated ore. Both materials seem to have replaced a siliceous cement in the quartzite. This analogy, together with the definite decrease in the amount of the oxides with increasing distance from the ore bodies, the gradational boundary between the altered wall rock and the bodies of disseminated ore, and the presence of calcite in the altered wall rock but not in the fresh quartzite—all point strongly to the development of some manganese-iron carbonate mineral or minerals in the wall rock as an accompaniment of the primary mineralization. It is believed that these manganese and iron oxides accompanied by calcite must represent a product of metasomatic alteration closely comparable to the well-known development of calcite adjacent to fissure veins.

The primary metasomatic mineral or minerals from which the oxides of iron and manganese and possibly also the calcite have been formed were not observed in any of the specimens. By inference, however, it seems probable that the primary mineral was manganiferous iron carbonate. Siderite, a mineral that commonly contains manganese, is abundant in many of the lead-silver deposits of Idaho, and in the Coeur d'Alene district[1] it replaces quartzite extensively.

[1] Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Coeur d'Alene district, Idaho: U. S. Geol. Survey Prof. Paper 62, pp. 95, 97, 1908.

LEAD-SILVER VEINS IN LIMESTONE.

GENERAL FEATURES.

Lead-silver veins in limestone are more numerous in the Mackay region than representatives of any of the other groups of deposits. In many of them replacement phenomena are so pronounced that they might equally well be classed as replacement deposits. In all, however, either fissures or bedding planes have exercised a dominant influence in directing the ore-depositing solutions and have given to the deposits a distinctly tabular form which justifies considering them as veins. Indeed it would be impracticable to attempt to draw a line of demarcation between the vein deposits and the replacement deposits, as different ore shoots in the same mine would require a different classification.

Lead-silver ores in limestone occur in the Skull Canyon and Birch Creek districts in the northeast corner of the area mapped; in the Clyde and Dome districts in Lemhi Range; in the Antelope district, southeast of Mackay; and in the Muldoon district in the southwest corner of the region. In all the deposits siderite accompanies quartz as a gangue mineral but is abundant only in the Muldoon deposits. Oxidation is well advanced as a rule and in few places has ground-water level been reached.

DEPOSITS EAST OF BIRCH CREEK VALLEY.

The principal lead-silver deposits east of Birch Creek valley occur on the Kaufman & Weaver claims in the Skull Canyon district and in the Birch Creek mine in the Birch Creek district. In both districts the ore deposits are inclosed in magnesian limestone. Three veins, two of them parallel but about 200 feet apart and the other at right angles to them, are believed to be indicated by the outcrops on the Kaufman & Weaver claims. One of these veins is about 4 feet wide as exposed in an 80-foot shaft and averages 20 to 30 per cent lead and 2 to 4 ounces of silver to the ton. Another vein is 30 inches wide, as exposed in a crosscut tunnel, and consists of galena, now altered to cerusite, cementing a fault breccia. The third vein is poorly exposed in the sides of a shaft, but in it replacement phenomena are more extensive than in the others. None of these veins is recognized in the lower tunnel which passes under at least two of the upper exposures. In several places, however, the tunnel crosses zones heavily stained with iron and manganese that are certainly worthy of further prospecting.

The ore as now exposed is completely oxidized and most of the lead occurs in the form of cerusite. The rare hydrous lead-iron sulphate plumbojarosite was recognized in these ores.

The Birch Creek deposits occur as a vein which traverses the formations in the upper workings, but in the lower levels follows the bedding of the inclosing limestone. The deposit is developed to a depth of 200 feet, and several shoots of ore have been discovered, the largest of which is 100 feet long, 3 feet wide, and averages 10 per cent lead. Some of the smaller shoots are of higher grade. The ore minerals are galena, cerusite, and anglesite, the last two associated in most places with an abundant yellowish-brown jasper-like gangue. Wulfenite occurs locally as brilliant orange-red crystals. Smithsonite is rare. The galena occurs as fine-grained variety steel galena and as coarse cubes. Nodules of the galena embedded in the jasper-like gangue are surrounded by a narrow band of anglesite, in part altered to cerusite, with which smithsonite is locally associated. Anglesite occurs also scattered through the gangue, locally as veinlets but in most places as small specks. On weathering the gangue material becomes first a limonite yellow and then porous and brown. The paragenesis of the several minerals of this type of ore is not entirely clear, although, from the hand specimens and the usual genesis of jasper, it seems most reasonable to suppose that the jasper-like material is later than the galena and that either during or preceding its deposition the alteration products of that mineral were formed. As the present workings are all well above ground-water level the geologic relations support this supposition.

The cerusite of the deposit has a peculiar grayish-black color, thought to be due to the manganese that it is known to contain.

The inclosing rock is recrystallized for a few inches back from the ore bodies in most places, which seems to indicate a higher temperature at the time of deposition than is common in veins of this type. This development of calcite adjacent to the ore bodies has every resemblance to the common marmarization of limestone near igneous contacts, and it seems only reasonable to interpret it as the result of a process at comparable temperatures. The ores themselves are in large part metasomatic replacement deposits, the material having been introduced, but the accompanying marginal band of carbonate minerals is believed to be simply a recrystallization of material already present.

DEPOSITS IN THE LEMHI RANGE.

Lead-silver deposits in the limestone formations of the Lemhi Range are known at two places about 15 miles apart, but neither has been extensively prospected. They are of interest, however, in that they afford additional information on the distribution of mineralization in the region. The deposits on Badger Creek, in the Clyde district, were not visited but are reported to have yielded a few shipments of lead-silver ore. In the Dome district development on the Johnson property has exposed several seams and small lenses of galena in limestone, although no body of commercial importance has been found. This property is situated 2 miles north of the Wilbert mine, where the extensive bodies of lead ore in quartzite occur.

DEPOSITS OF THE MULDOON AND ANTELOPE DISTRICTS.

The deposits of the Muldoon district occur in limestone and to a minor extent in slate and quartzite; they are said to be closely associated with a dike of granite porphyry. Much pyrite accompanies the galena, and the silver averages perhaps 1½ ounces for each per cent of lead—a much greater amount than that in any of the lead-silver deposits in the northern part of the Mackay region, although about the same as in those of the Wood River district. The deposits were visited by E. H. Finch, whose report appears in another section of this paper (p. 106). Perhaps the most interesting feature of the ores is the large amount of sericite developed in the rock that the ore replaces.

The Antelope deposits were not being worked in 1912, and the workings were inaccessible, but they were reopened in 1913, and about 1,000 tons of ore, averaging 16 per cent lead and 16 ounces of silver to the ton, were shipped. The ore bodies occur along a northward-trending vein which dips westward beneath a capping of eruptive rock.

LEAD-SILVER VEINS IN GRANITE PORPHYRY.

The lead-silver deposits in granite porphyry occur in the Alder Creek district, and are of particular interest because of their close association with contact-metamorphic deposits of copper. The lead ore here contains about one-third of an ounce of silver for each per cent of lead and in the Grand Prize vein consists of galena in a siderite gangue. This vein is from 6 inches to 2 feet wide. No evidences of contact metamorphism were observed in specimens on the dump, but about 1,200 feet away, along the general course of the fissure, garnet and magnetite are extensively developed both at the surface and to a depth of at least 700 feet, as shown in the Alberta tunnel and in material said to have come from the bottom of the Darlington shaft. Lenses of lead-silver ore in the granite porphyry also occur in the Horseshoe and Kennedy groups of claims.

The occurrences of lead ore in the granite porphyry are of special interest because of their relation to a central area of contact copper deposits as brought out on page 79.

TUNGSTEN VEINS.

Tungsten-bearing veins have been discovered recently near the head of Lava Creek in the Lava Creek mining district. The following notes on the deposits were obtained by the study of specimens sent to the Survey by Robert N. Bell, State inspector of mines, and from correspondence with men acquainted with the district.

The principal vein strikes northwest and dips steeply to the northeast. It is about 5 feet in average width and is made up of veinlets and bunches of quartz in a crushed igneous rock which may be the marginal phase of a granite mass known to crop out in this vicinity. The igneous rock is intensely altered, and sericite and chlorite are abundantly developed. Hübnerite is the principal ore mineral in the specimens examined and occurs as platy aggregates and isolated plates in the quartz. The quartz is coarse textured and in several specimens occurs as elongated crystals oriented parallel to the walls of the veinlets and pointing toward a well-defined median plane with drusy surfaces. Vugs lined with quartz appear in several of the specimens, many of which are stained with oxides of iron and manganese.

The vein is said to occur between a footwall of granite and a hanging wall of limestone.

GENESIS OF THE PRE-OLIGOCENE ORE DEPOSITS.

The origin of the contact deposits has been discussed at length elsewhere (pp. 68–79), so that it only remains to consider the genesis of the vein deposits and to point out the genetic relation between the two types. It has been shown that the granite porphyry exposed in the vicinity of White Knob is the direct source of the contact ores and that great quantities of alumina, silica, iron, copper, sulphur, fluorine, and other substances escaped from the magma after the solidification and fracturing of its outer part. Veins of lead-silver ores are closely associated with the contact copper ore, some of them being inclosed in the igneous rock from which, at greater depth, the solutions emanated. Similarly, in the Muldoon district, contact and vein deposits are clearly related to a granitic batholith, which also crops out to the north in the vicinity of the Lone Star lead-silver vein. Thus, by the proximity of the veins in the southwest part of the region to contact deposits, which clearly represent emanations from a granitic magma, and their occurrence locally within the contact zone, it is concluded that all the ores in this part of the region, except those of late Tertiary age, are closely related genetically and that a batholithic mass, which crops out only locally, supplied the material.

It is noteworthy, however, that no similar igneous rock is known in the northeast part of the region, where veins with similar characteristics are recognized over a wide area. Here there is nothing of structure or rock composition different from the vast barren belt represented by the Lost River Range, which extends across the central part of the region in a northwest course. The same Paleozoic rocks, though perhaps more complexly faulted and folded in the Lost River Range, occur in both areas and the rocks in large part represent the same horizons in the stratigraphic section. In the Dome district quartzite, an unfavorable host for replacement deposits, contains the ores, and in the Birch Creek mine the limestone along the vein is marmarized, indicating more intense heat and pressure here than elsewhere. The distribution of the deposits suggests that the ore-depositing solutions were supplied locally, and, because of this localization in rocks that retain their characteristics into wide areas in which ore is absent, that the ore material was introduced from a source other than the present host. The ores themselves are similar to those in the southwest part of the region, where their igneous derivation is clear, and as they are obviously not dependent upon the type of inclosing rock nor fundamentally upon its structure it seems necessary to postulate an underlying body of granitic rock in the northeast part of the region, whence the ore solutions sprang. Such a mass may reasonably be supposed to underlie Lemhi Range and to extend east beneath the Birch Creek valley and the mountain range beyond. Igneous rocks are known in areas a short distance to the north along these ranges, in the Spring Mountain, Texas, and Nicholia districts,[1] and similar ore deposits in the Birch Creek valley have been thought to be related to them.

POST-OLIGOCENE ORE DEPOSITS.

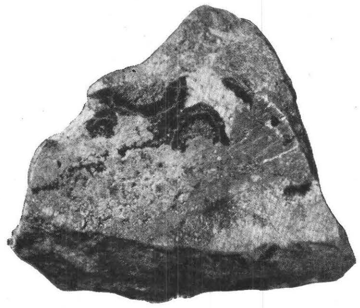
DISTRIBUTION AND CHARACTERISTICS.

Ore deposits of post-Oligocene age occur in the Era and Lava Creek districts, situated in the extreme south-central part of the Mackay region. These districts comprise adjacent segments of the rugged slope, which rises abruptly from the broad lava-flooded basin of Snake River, at an elevation of about 5,300 feet, to the highland area whose summits are approximately 10,000 feet above sea level. Within the area of these districts the mountain front, in most places made up of Paleozoic and Mesozoic rocks, is carved from Miocene lavas and related tuffs, which inclose the ore deposits.

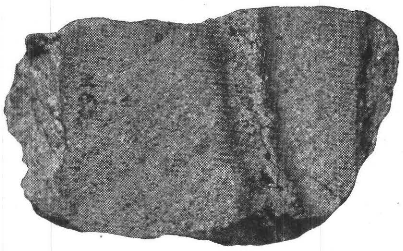
The veins of these districts belong to that group of deposits which in many places have been shown to be of late Tertiary age. The group as a whole is fairly well characterized by a gangue of cryptocrystalline quartz and chalcedony, the crustified structure of the vein matter, sericitization of the wall rock, predominance of the precious metals in the ore, lamellar calcite commonly replaced by quartz, and association with Tertiary lavas. In these districts, however, the base metals are abundant, argentiferous galena being the chief ore mineral in some of the veins, and for this reason the deposits are of particular interest.

The inclosing rocks comprise rhyolite, andesite, and related tuffs and are believed to be of Miocene age. The veins in general extend north and south and dip either to the east or to the west. They range in width from mere stringers to 5 feet or more but have not been found to extend more than perhaps 100 feet below the surface. The principal metallic minerals observed in them are galena, sphalerite, wurtzite, pyrite, chalcopyrite, proustite, tetrahedrite, argentite, cerargyrite, smithsonite, and cerusite; the last three are secondary but the others are primary, at least in most places. Three of these minerals, pyrite, sphalerite, and wurtzite, occur also in the wall rock as replacements of the minerals of the inclosing lavas and tuffs. Manganese and iron oxides form abundant stains, both in the wall rock near the veins and in the upper part of the ore bodies. The predominant gangue minerals are cryptocrystalline quartz and chalcedony, although in some of the veins calcite is abundant and locally barite, probably secondary, occurs. In most places the veins are bordered by sharply defined walls, but in the St. Louis mine, in the Era district, the galena-wurtzite-sphalerite ore grades through a band half an inch to a few inches wide into the inclosing rhyolite. (See Pl. XX, *B*.) Here the wurtzite, and in most places the sphalerite, is fine grained and without crystal boundaries, but locally the wurtzite occurs in peculiar spherical masses one-quarter to one-half inch in diameter. In cross section these masses are seen to be made up of an outer band of dark-brown dense wurtzite separated from a large central light-brown area by a dense black layer, also of wurtzite. The inner light-brown part is rather spongy in texture and has a distinctly radial structure, the interstices being filled by calcite. These spherical bodies of wurtzite occur in the unaltered galena ore and are traversed locally by veinlets of galena, indicating that the zinc sulphide was the earlier to form. (See Pl. XX, *A*.) Sphalerite, at least in part, formed earlier than the pyrite, as shown by its central position in phenocrysts of the wall rock replaced otherwise by that mineral. All the available evidence points to the contemporaneous formation of the sphalerite and wurtzite. It is not believed that either mineral is an alteration product from the other, although Plate XX, *C*, offers some suggestion that the wurtzite may be secondary after the sphalerite.

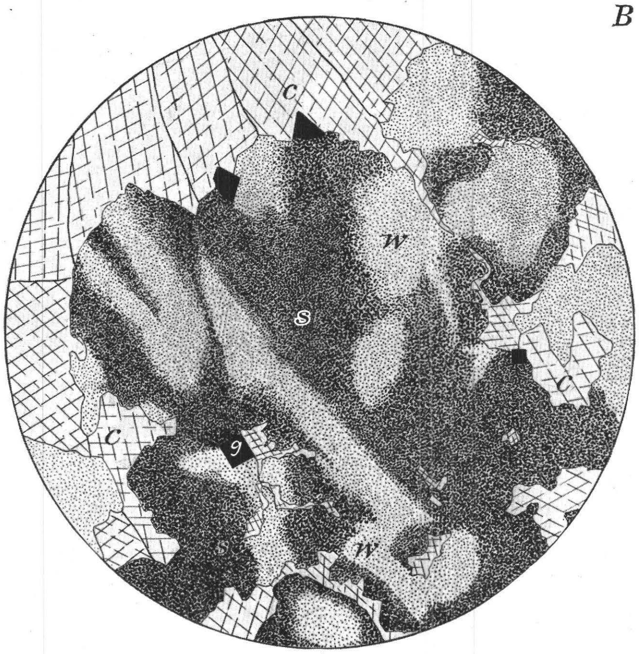
[1] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, p. 42, 1913.



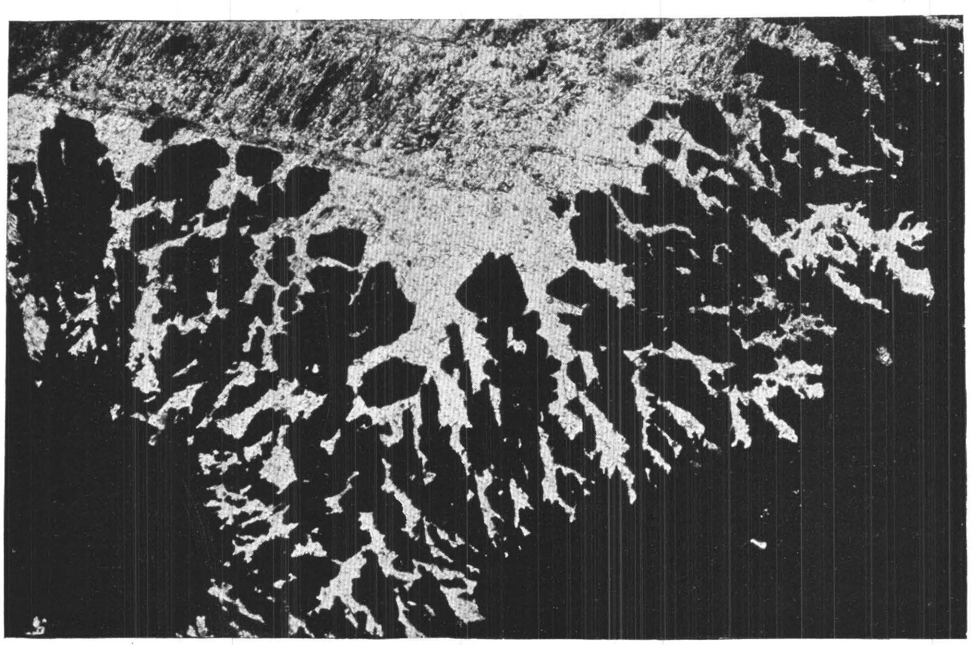
A



B



C



D

SPECIMENS OF ORE FROM ST. LOUIS MINE, ERA DISTRICT, IDAHO.

A. Wurtzite spherules truncated by galena (light). Natural size.
B. Galena-sphalerite-wurtzite veinlet replacing sericitized andesite. Natural size.
C. Intimate intergrowth of sphalerite (*s*) and wurtzite (*w*), possibly after calcite (*c*) and replaced by galena (*g*). Camera lucida drawing. × 250.
D. Intergrowth of wurtzite (dark) and calcite, proving their contemporaneous development. Section taken from specimen shown in *A*. × 250.

ALTERATION OF THE WALL ROCK.

A characteristic feature of the deposits is the intense sericitization and noteworthy silicification of the inclosing rock. The sericite occurs as felted aggregates in areas of feldspars and as minute flecks scattered thickly through the groundmass. In places also it occurs within the area of quartz grains, but this is not common in the thin sections examined. Specimens of the wall rock next to the vein are silicified, the quartz apparently having replaced first the groundmass and then the feldspars and other phenocrysts except quartz, to grains of which it is locally added as aureoles. In general the silicification does not appear to extend nearly as far from the veins as does the sericitization, although too few specimens were available to establish the relation. Chlorite has been developed sparingly in specimens of wall rock from the St. Louis mine.

Replacement of the wall rock has played an active part in the formation of some of the ore bodies. In many places in the St. Louis mine there is an absolute gradation from sericitized wall rock to ore made up entirely of galena, wurtzite, sphalerite, and small amounts of pyrite. The transition zone in most places is about one-half inch wide, and in it galena, sphalerite, wurtzite, and pyrite are about equally abundant, the galena and zinc sulphide increasing in relative amount toward the vein and the pyrite toward the walls. This band also presents a perfect gradation in color from the light gray of the rhyolite to the bluish black of the vein matter. During the replacement the groundmass of the rhyolite seems to have been the first part to alter, then the feldspar phenocrysts, quartz being most resistant and in places even remaining in the ore as embayed crystals similar in shape to the phenocrysts of the normal rhyolite. In places, however, the vein matter is free from quartz, suggesting that locally it, too, has been entirely replaced.

The genesis of the sulphides of zinc has been the subject of exhaustive synthetic study by Allen and Crenshaw,[1] who conclude that sphalerite crystallizes from alkaline solutions and at temperatures above 300° C. from acidic solutions, but that wurtzite is formed only from acidic solutions. This latter conclusion is in accord with observations already recorded on the occurrence of wurtzite. With the possible exception of the Goldfield deposits local relations have invariably suggested that the wurtzite formed from descending acidic solutions. Ascending ore-depositing solutions have been quite generally regarded as alkaline, both because of the types of alteration of the wall rock accomplished by them and because if they were acidic initially it is believed that in most deposits they would soon become alkaline through contact with the alkali silicates or other basic constituents in rocks which they traverse. If, then, the wurtzite in these deposits indicates acidic solutions, and it is believed to have been deposited along with the primary minerals, the genesis of the deposits is somewhat exceptional, although in a few other localities ascending acidic solutions have been postulated. The intense alunitization of the rock inclosing the Goldfield ores led Ransome to believe that ascending sulphydric acid became oxidized to sulphuric acid at and near the surface, and that this percolated down through the warm rocks to mingle with the hot ascending solutions charged with hydrogen sulphide, the deposition of gold and the alunitization of the wall rock resulting from this mingling.[2] The alunite veins near Marysvale, Utah, are thought by Butler probably to have been deposited by ascending sulphate solutions, although he states that "the possibility of the sulphuric acid having been produced by the oxidation of hydrogen sulphide or other sulphur compounds can not be eliminated."[3]

SIGNIFICANCE OF WURTZITE IN THE ORES.

The presence of wurtzite, the hexagonal form of zinc sulphide, in the ores of the late Tertiary veins was not suspected in the field and comparatively little of the material was collected. In each of the six hand specimens containing zinc sulphide, however, the mineral has been identified in noteworthy amounts and seems to warrant the belief that it is an essential constituent of the deposits and probably the dominant form of zinc sulphide. It occurs intimately associated with sphalerite, the isometric form of zinc sulphide, and with galena

[1] Allen, E. T., and Crenshaw, J. L., The sulphides of zinc, cadmium, and mercury; their crystalline forms and genetic conditions: Am. Jour. Sci., 4th ser., vol. 34, pp. 341-396, 1912.

[2] Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, pp. 189-199, 1909.

[3] Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: U. S. Geol. Survey Bull. 511, pp. 34-37, 1912.

and pyrite, in places entirely surrounded by these minerals, or as distinct grains intergrown with them, locally as spherical masses traversed by veinlets of galena (see Pl. XX, *A*) and elsewhere as parts of apparently continuous veins, other parts of which are sphalerite. (See Pl. XX, *B*.) This interrelationship occurs not only in the vein material proper, but within patches of ore minerals that unquestionably replace the igneous wall rock, locally more than an inch from any veinlet. It is believed that the three sulphide minerals are essentially contemporaneous in origin, and manifestly they represent the primary mineralization which accompanied the introduction of large quantities of potash into the wall rock and the consequent extensive development of sericite. (See Pl. XX, *A* and *B*.) The wurtzite in places occurs in delicate fretwork that carries calcite in its interstices, indicating that the zinc and lime existed in the same solution. It also bears a similar relation to quartz.

Particular interest in this connection attaches to the occurrence of wurtzite in the Goldfield ores on account of their supposed deposition from acidic solutions. Sulphide of zinc is not abundant in this district, and in the original description, made before the significance of wurtzite, the comparatively rare form, was known, all of it was considered to be sphalerite. In a recent paper, however, Ransome calls attention to this mineral in some of the material originally collected by him, as follows:[1]

> The so-called sphalerite is dark reddish brown, forms crusts rarely over half an inch thick and in places it shows a rather indistinct fibrous structure. * * * In this section under the microscope a considerable part of the material, particularly that forming the inner portion of the crust, may be seen to consist chiefly of radial aggregates of distinctly birefringent prisms with very indefinite individual outlines. These fibers, which are clearly wurtzite, show a tendency to diverge from points on the inner surface of the crust, becoming less distinct toward their free ends, where the birefringent aggregate grades into material that is chiefly sphalerite, containing here and there little flecks of wurtzite. In some aggregates the prisms have grown radially outward from small dark nuclei, which appear to consist chiefly of ferruginous zinc sulphide, in part at least wurtzite. As a rule the aggregates of wurtzite in addition to their radially fibrous structure, show a noticeable although discontinuous concentric parting.

A search through the collection from the late Tertiary veins of the Mackay region for alunite, marcasite, primary barite, or any other evidence of primary acidic solutions has proved fruitless, and so far as it has been possible to carry the studies with the specimens available it must be concluded that if the primary solutions were acidic, as is suggested by what is known of the genesis of wurtzite, no corroborative evidence of this acidity has been found. From the amount of sericite in the wall rock it seems necessary to conclude that potash was an abundant constituent of the solutions and it is known that the constituents of calcite were also locally abundant. With potash and lime present in large amounts in the solutions and also in the rocks which they traversed it is difficult to see how the primary solutions could have been acidic.

It remains to consider, however, whether the wurtzite may not have resulted through a molecular rearrangement of the sphalerite under the action of descending acidic solutions. The specimens present every appearance of fresh primary ore. The pyrite is unaltered and its surfaces are brilliant, and the sphalerite, wurtzite, and galena show no margins of alteration. Furthermore, small specks of wurtzite totally surrounded and protected by other primary sulphides are abundantly developed. Wurtzite also occurs as isolated grains in the wall rock, and in narrow veinlets well removed from the main fissure. On the other hand, sphalerite exists in many places in the main fissure where weathering agencies would be expected to operate first. In consequence of these considerations it is believed that the wurtzite and sphalerite were both deposited by the ascending primary solutions, although the evidence is perhaps not altogether conclusive.

Specimens of the Goldfield ores also yield only inconclusive evidence of the paragenetic relations of the two forms of zinc sulphide. In his discussion of their occurrence F. L. Ransome[2] says:

> The suggestion is favored that the wurtzite is later than the sphalerite and represents a molecular rearrangement of that mineral. But the explanation originally offered[3] for the deposition of the ore through a mingling of alkaline and acid solutions is quite in harmony with the supposition that the sphalerite and wurtzite crystallized at approximately the same time.

---

[1] Ransome, F. L., Wurtzite at Goldfield, Nev.: Washington Acad. Sci. Jour., vol. 4, No. 16, pp. 482-484, 1914.

[2] Idem, p. 485.

[3] The geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, p. 196, 1909.

The same possibilities were entertained by B. S. Butler in his studies of the Hornsilver mine, but he concludes that although the wurtzite is a secondary mineral it is not of enantiotropic origin, but rather that the zinc which it represents

has been introduced into the zone where it occurs after the formation of the sphalerite and on precipitation has formed around the sphalerite, which has furnished centers of crystallization, and to a less extent has crystallized from new centers.[1]

The genesis of wurtzite has recently been reinvestigated synthetically by Allen and Crenshaw,[2] with the result that their former conclusions were confirmed and new data determined. In this paper wurtzite from the Mackay region and marcasite from Crystal Cave, Joplin, Mo., are commented on as follows:

The nature of these crystals indicates that they did not develop in free space, but that they crystallized simultaneously with calcite. If so, the marcasite and wurtzite must have crystallized from solutions containing no stronger acid than carbonic acid, and probably at the ordinary temperature. It should be borne in mind that all the solutions used in our experiments, though dilute in some cases, were incontestably acid or incontestably alkaline, so that the specific influence of each is unquestionable. The nearest approach to the above conditions we have been able to employ are given on page 404, where we found that pure marcasite, or at any rate very nearly pure marcasite, was obtained from a solution containing 0.015 per cent sulphuric acid. Between this degree of acidity and very slightly alkalinity at ordinary temperatures there exists a very narrow field which has not been explored, nor does it present a promising field for exploration. We only know that in solutions containing only hydrogen sulphide, and therefore close to neutrality (reaction with ferric hydroxide suspended in water), pyrite is obtained at 150°.

We have also shown that wurtzite, in the temperature interval where it could be crystallized, was formed from acid solutions, and the concentration of the acid demanded for the inhibition of sphalerite grows less with descending temperature, as it does with pyrite.

The diverse opinions outlined above, and the fact that zinc sulphide is one of the few ore compounds that has been the subject of exhaustive synthetic investigation, emphasize the great desirability of careful field observations on the paragenetic relations of wurtzite. This form of zinc sulphide has probably been mistaken for sphalerite in many deposits because in most occurrences the two minerals are identical in megascopic appearance and because thin sections are not usually prepared of opaque ores. It seems that most of the described occurrences of wurtzite may be explained by the synthetic experiments, but the results of these studies should be further tested by field observations before they can be given full weight in deciding problems of ore genesis.

[1] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah, p. 150, 1913.

[2] Allen, E. T., and Crenshaw, J. L., Effect of temperature and acidity in the formation of marcasite (FeS_2) and wurtzite (ZnS): Am. Jour. Sci., 4th ser., vol. 38, pp. 393-431, 1914.

SIMILAR DEPOSITS.

The late Tertiary veins, characterized by features generally considered as due to deposition at a moderate depth, are predominantly valuable for gold and silver; base metals in them in commercial amounts are exceptional, although several occurrences are known. In most of these veins galena, sphalerite, and tetrahedrite occur only in accessory amounts, but in one carefully described deposit, the Los Pilares mine, in Mexico,[3] large bodies of pyrite and chalcopyrite are accompanied by a very little zinc, no lead, a trace of gold, and less than an ounce of silver to the ton. The veins of the San Juan region, Colo., although in most places worked for gold and silver, are locally rich in galena, sphalerite, and tetrahedrite or enargite.[4] Of the late Tertiary deposits the ones at Creede correspond perhaps more closely than any of the others to the veins of the Mackay region. Here most of the production has come from persistent silver-lead fissures in rhyolite. The ore minerals include zinc blende, argentiferous galena, pyrite, and chalcopyrite in a gangue of quartz which carries also chlorite, barite, and fluorite. The ores were formed principally in open spaces but "at some places near the veins * * * the intensely altered replaced rhyolite constitutes good ore."[5]

Lindgren cites one foreign occurrence, the Schemnitz deposits in Hungary, that belongs to this type. Here there is a "strong vein system intersecting rhyolite and andesite above Triassic slates and Eocene strata." Abundant pyrite, galena, chalcopyrite, and zinc blende occur in a gangue principally made up of cryptocrystalline quartz and amethyst.[6]

[3] Emmons, S. F., Los Pilares mine, Nacozari, Mexico: Econ. Geology, vol. 1, pp. 629-643, 1906.

[4] For a summary description and bibliography of the San Juan region, see Lindgren, Waldemar, Mineral deposits, pp. 497-506, 1913; or Spurr, J. E., and Garrey, G. H., Economic geology of the Georgetown quadrangle, Colo., with general geology, by S. H. Ball: U. S. Geol. Survey Prof. Paper 63, pp. 111-117, 1908.

[5] Emmons, W. H., and Larsen, E. S., A preliminary report on the geology and ore deposits of Creede, Colo.: U. S. Geol. Survey Bull. 530, pp. 42-65, 1913.

[6] Lindgren, Waldemar, Mineral deposits, p. 496, 1913.

ORE MINERALS OF THE MACKAY REGION.

The ore minerals of the Mackay region have been discussed under particular types of deposits. This information, however, is scattered through the report, and to make it more available a list of the minerals with the occurrence of each indicated in tabular form is added. The minerals are arranged alphabetically, each with its composition, nature (primary or secondary), and the type of deposit in which it occurs.

Sixty-seven mineral species directly connected with the ores of the region are recognized, and manifestly the list, which is based on reconnaissance work, is probably far from complete. The contact deposits contain the greatest variety of minerals, and in them most of the minerals found elsewhere also occur. The mineralogy of the veins is simple, although the occurrence of plumbojarosite in the Skull Canyon district and of primary wurtzite in the Era district are of special interest. The mineralogy of the tungsten veins as given is doubtless very incomplete, as it is based entirely on a few small specimens sent to the Survey.

The letters used in the table indicate that the mineral occurs, A, abundantly; S, sparingly; R, rarely.

Ore minerals of the Mackay region.

Mineral.	Composition.	Pre-Oligocene deposits.								Post-Oligocene deposits.		Remarks.
		Contact deposits.		Lead-silver veins.		Copper veins.		Tungsten veins.		Silver-lead veins.		
		Primary.	Secondary.	Primary.	Secondary.	Primary.	Secondary.	Primary.	Secondary.	Primary.	Secondary.	
Actinolite	$CaO.3(MgO.FeO).4SiO_2$	S										
Andradite	$3CaO.Fe_2O_3.3SiO_2$	A										See p. 50.
Anglesite	$PbSO_4$				S		R				S	
Apatite	$Ca_4(CaF)(PO_4)_3$	R										
Argentite	Ag_2S				R						S	Said to have been abundant in Muldoon district.
Arsenopyrite	FeAsS			R								Muldoon district.
Augite	Complex silicate	A										
Azurite	$2CuCO_3.Cu(OH)_2$		A		R		A					
Barite	$BaSO_4$			S?		S?	S				S	Skull Canyon and Era districts.
Bornite	Cu_3FeS_3		S				S					
Brochantite	$Cu_4(OH)_6SO_4$		A									Alder Creek district.
Calamine	$(ZnOH)_2SiO_3$		R		S						S	
Calcite	$CaCO_3$	A		S		S				A		
Cerargyrite	AgCl				R						A	Hornsilver mine.
Cerusite	$PbCO_3$				A		R				A	
Chalcanthite	$CuSO_4.5H_2O$		R									Alder Creek district.
Chalcedony	SiO_2									A		
Chalcocite	Cu_2S		R				S					
Chalcopyrite	$CuFeS_2$	A		R		A				R		
Chlorite	Complex silicate		S							S		
Chrysocolla	$CuSiO_2.2H_2O$		A		R		A					See p. 51.
Copper	Native		R				R					
Copper pitch	Mixture		R				R					

Ore minerals of the Mackay region—Continued.

Mineral.	Composition.	Pre-Oligocene deposits.								Post-Oligocene deposits.		Remarks.
		Contact deposits.		Lead-silver veins.		Copper veins.		Tungsten veins.		Silver-lead veins.		
		Primary.	Secondary.	Primary.	Secondary.	Primary.	Secondary.	Primary.	Secondary.	Primary.	Secondary.	
Covellite	CuS		S				R					Plate XVI, *D*.
Cuprite	Cu_2O		S				R					See p. 52.
Custerite	$Ca_4Si_2H_2F_2O_8$	S										See p. 52.
Diopside	$MgCa(SiO_3)_2$	A										
Epidote	Complex silicate	S		S								Alder Creek and Muldoon districts.
Fluorite	CaF_2	A										Alder Creek district.
Galena	PbS	R		A		S				A		
Gold	Native	R		R		R		R		R		All the ores carry a little gold.
Grossularite	$3CaO.Al_2O_3.3SiO_2$	A										
Gypsum	$CaSO_4$		S				R					
Hedenbergite	$CaFe(SiO_3)_2$	S										
Hematite	Fe_2O_3		A		A		A		S		S	
Hübnerite	$MnWO_4$							A				
Jasper	Impure SiO_2				A		S					See p. 84.
Kaolinite	$H_4Al_2Si_2O_9$		R									
Limonite	$2Fe_2O_3.3H_2O$		A		A		A		A		A	
Linarite	$CuPbSO_4.H_2O$				R							Wilbert mine.
Magnetite	Fe_3O_4	A										
Plagioclase	Variable silicate	R										
Plumbojarosite	$PbFe_6(OH)_{12}(SO_4)_4$				R							Kaufman & Weaver mine.
Proustite	Ag_3AsS_3										R	
Pyrite	FeS_2	A		S		A		S		A		
Pyrolusite	MnO_2		S		A		S		S		S	See p. 82.
Pyrrhotite	Fe_nS_{n+1}	A										
Quartz	SiO_2	S		A		A		A		A		
Scapolite	Complex silicate	R										
Sericite	$H_2KAl_3(SiO_4)_3$	R		?		?		?		A		
Serpentine	$H_4(Mg,Fe)_3Si_2O_9$		A									
Siderite	$FeCO_3$			A		S						Muldoon and Grand Prize mines.
Smithsonite	$ZnCO_3$				S		R				S	
Specularite	Fe_2O_3	A										
Sphalerite	ZnS			S		R				A		
Tenorite	CuO		R									
Tetrahedrite	$Cu_8Sb_2S_7$		R?	S						S		
Titanite	$CaSiTiO_5$	R										
Tremolite	$CaO.MgO.4SiO_2$	S										
Vesuvianite	Complex silicate	S										
Wollastonite	$CaSiO_3$	S										
Wulfenite	$PbMoO_4$				S		R					Weimer and Birch Creek mines.
Wurtzite	ZnS									A		Era district.

PRACTICAL CONCLUSIONS AND SUGGESTIONS TO THE PROSPECTOR.

A general survey of the geologic relations and ore deposits of the Mackay region suggests three principal areas that are worthy of further careful prospecting. In these areas structural relations are favorable to ore deposition and the deposits now known indicate an intense mineralizing activity at the time the ores were formed. One of the areas comprises that portion of the range east of Birch Creek valley, from the Kaufman & Weaver property south to the Birch Creek mine. The deposits in this area have been inadequately explored but near the surface contain lead-silver and copper ores of excellent grade. Except for three developed mines there is very little evidence of prospecting in the area.

An area of greater promise than the one just mentioned is the Dome district, situated near the south end of the Lemhi Range. Here one mine, the Wilbert, has developed large bodies of lead-silver ore in quartzite, generally recognized as an unfavorable host for lead ores if limestone is available. Not far from the lead deposits in quartzite there are large areas of limestone which were involved in the same crustal movement that formed the fractures along which the lead-depositing solutions traveled. Moreover, prospects occurring at intervals for 2 miles to the north and an even greater distance to the south indicate that mineralization in the district is somewhat general. For these reasons, and because comparatively little prospecting has been done in the area, it is believed that other important deposits may be found in the vicinity. In searching for them the conclusions stated on page 118 should be kept in mind, for there are unquestionably at least two periods of faulting represented in the area, one, earlier than the deposits, to which they are definitely related, and another, later than the deposits and hence of less significance in prospecting for them. The earlier faults, as now known, have reverse throw, but the later are normal displacements, a relation that may be expected to hold throughout the district. Thus, if a fault is found along which the hanging wall has moved up relative to the footwall its outcrop should be followed in search of material stained heavily with oxides of iron and especially oxides of manganese. For the prospector difficulty will probably be experienced in distinguishing between a normal and a reverse fault, which can only be overcome by gaining an acquaintance with the local rock succession. (See Pl. XVIII, p. 80.) It will probably be found that in this vicinity most of the reverse faults are associated with the axis of a sharp fold in the beds.

Another area worthy of further prospecting, and perhaps the most favorable one, extends from Mackay southwestward to Copper Basin and thence south to Muldoon. In this area the granitic masses, which crop out locally and probably extend beneath the entire area, are the direct cause of the mineralization. The solutions, however, did not escape from them at all points; two principal centers of mineralization are recognized at present, one north of White Knob and the other on the north side of Copper Basin. The ore-forming solutions escaped through fractures developed after the outer few hundred feet of the magma had solidified, and it seems unreasonable to think that their escape was permitted in noteworthy amounts only in these two localities. Much of this area is comparatively inaccessible, and in several places where limonite and iron-stained quartz were observed in the soil no prospect pits were seen. This dearth of prospect openings does not apply so much to the slope facing the valley of Big Lost River as it does to the area between White Knob and Copper Basin and southward. In the area north of Copper Basin contact-metamorphic replacement deposits are likely to occur, and their surface indications may be expected to be similar to those at the Empire mine. An iron-stained soil that contains fragments of jasper-like material should be considered an encouraging indication, especially if the fragments react for copper.[1] As the contact ore bodies are of irregular shape, an outcrop of irregular outline instead of a sharply defined lode must be expected. In any area about these granite or granite porphyry masses where garnet rock occurs the outcrops should be carefully searched for indications of copper. The most likely places to look for them are along the contact of the igneous rock and limestone and about blocks of limestone surrounded by the igneous rock. In such situations copper may occur either in the igneous or in the sedimentary rock, but is most likely to be found in the transition zone between garnet rock and unmetamorphosed limestone. Portions of the limestone that rest on the igneous mass present favorable situations for the occurrence of ore, and as the granite porphyry is believed to spread out below the surface it follows that contact deposits may be found well removed

[1] The presence of copper in this form may be determined as follows: Powder and dissolve in hydrochloric acid, then add caustic ammonia. If the solution turns deep blue, copper is present. If much iron is present, its heavy brown precipitate may mask the copper color, but if allowed to stand, the iron will settle to the bottom and the solution above it will indicate the presence or absence of copper. The quantity of copper must be determined by assay.

from any exposure of the igneous rock, as on the Reed & Davidson property.

Lead-silver veins may be found in this same area, but they are most likely to occur farther away from the igneous bodies than the copper ores. The most reasonable places to look for them is within the areas of the Paleozoic rocks, especially their limestone members.

MINING DISTRICTS OF THE MACKAY REGION.

In the following pages each of the ten mining districts in the Mackay region is dealt with separately. The order of treatment is based on the scheme of classification followed in the general discussion of the ore deposits. This arrangement groups the contact deposits among the districts described first; the older veins of copper and lead follow; and the two districts containing late Tertiary veins come last.

ALDER CREEK OR MACKAY DISTRICT.

SITUATION.

Alder Creek district is an unorganized mining subdivision containing about 75 square miles, situated in southeastern Custer County, Idaho, at the terminus of a 96-mile branch of the Oregon Short Line Railroad. Mackay, a town of perhaps 1,500 inhabitants, is the principal settlement and is situated in the valley of Big Lost River on the northeast edge of the district. The old town of Houston, prominent in the early history of the region, is 3 miles southeast of Mackay.

The Empire Railroad, owned and operated by the principal mining company of the district, extends from Mackay 7¾ miles southwest to the mine, which is 2,000 feet higher.

HISTORY.

The history of the district is essentially the history of the mine of the Empire Copper Co. Copper ore was discovered near the Darlington shaft about 1884, and soon thereafter W. A. Clark bonded the property and built a 50-ton smelter in the canyon of Cliff Creek. This smelter ran intermittently and with varying success for a few years, when the mine passed into the control of Wayne Darlington, who interested Eastern capital in its development. Operations were inaugurated on a large scale about 1901, and a smelter with two 125-ton blast furnaces was built at Mackay. The endeavor was to make black copper, but the furnaces were so proportioned that draft was almost impossible, and after running 30 days on 2 per cent ore and failing to reduce the slag content below 1.4 per cent copper, matting was adopted. For this purpose sulphide ore was shipped from Butte, Mont., but the financial losses were great and at the end of 10 months operations ceased.

In June, 1905, the present manager, Frank M. Leland, was placed in charge and made a four-months' run which netted between $50,000 and $60,000, the first profits from the mine after an expenditure of about $3,000,000. In November of the same year the MacBeth Lease, Inc., secured a five-year lease on the mine and smelter without royalty, and immediately let numerous subleases, a method since proved to be very successful in operating the property. One furnace was blown in March 5, 1906, and continued to run until August 29, 1907, when, owing to complaints of the ranchers against smoke, and of fishermen against slag dumped into the river, the smelter was again closed. During this run the matte carried about 40 per cent copper and 25 ounces of silver and 1 ounce of gold to the ton. Since 1907 the ore, nearly all of which is oxidized, has been shipped to smelters at Salt Lake, the cost of shipping and smelting there and that of local smelting being nearly the same.

During the period from about 1900 to 1907 the leading property of the district was owned and operated by a succession of White Knob corporations, which, though under the same general management, succeeded each other at short intervals, each a failure more disastrous than the one preceding it. Prior to 1905 more than $3,000,000 is said to have been spent on the property, and at one time the stock sold for $23 a share on a capitalization of 600,000 shares, yet not until 1905, when operated by a leasing company, was the mine ever worked on a business basis or at a profit. The Empire Copper Co., capitalized at $1,200,000, shares $1 par, acquired the mine and smelter on May 29, 1907, and since then it has been operated successfully through numerous leasers; in the summer of 1912 more than thirty leases were being worked.

PRODUCTION.

The production of the district has consisted almost entirely of copper and associated gold and silver, though a small amount of lead-silver ore has been shipped from the Easlie, Horseshoe, and Champion groups. The production has come almost entirely from the Empire mine, which under the old companies produced perhaps $500,000 and under the present company about $2,000,000 previous to the close of 1913. In 1913 the company and lessees shipped 34,721.69 dry tons of ore having an average assay value of 5.37 per cent copper and 0.052 ounce gold and 2.968 ounces silver to the ton. Of the total amount approximately $100,000 has been derived from gold, $200,000 from silver, and the remainder from copper.

LITERATURE.

The district has been the subject of brief mention in the mining journals at many times, but only one article deals at length with the geology of its ore deposits. This was published in 1907 and was based on the laboratory studies of J. F. Kemp and the field work of C. G. Gunther.[1] It contains a discussion of the contact metamorphism which characterizes the deposits and several diagrams illustrating the occurrence of the ore. Although the present studies have led to some conclusions which because of differences in field observations are fundamentally different from those of the earlier writers, yet their paper has been a very great help in preparing the present report. The writer differs from them in believing (1) that the "granite" and "quartz porphyry" are the same intrusion; (2) that the principal metamorphism took place after the consolidation of at least the outer 700 feet of the magma; and (3) that engulfed blocks of limestone determined the centers of metamorphism.

The history of the different White Knob companies and much other information concerning the district has been compiled by Stevens.[2] Other useful sources of information are the several annual reports on the mining industry of Idaho by Robert N. Bell, State inspector of mines, Boise, Idaho.

[1] Kemp, J. F., and Gunther, C. G., The White Knob copper deposits, Mackay, Idaho: Am. Inst. Min. Eng. Trans., vol. 38, pp. 269-296, 1908 (Am. Inst. Min. Eng. Bimonthly Bull. 14, pp. 301-328, 1907).

[2] Stevens, H. J., The Copper Handbook, vol. 8, pp. 664-665, 1426-1428, 1908.

FIELD WORK.

The writer spent 12 days in the district in August and September, 1912, during four of which he was assisted by C. H. Gray. In June, 1913, the district was revisited for a period of three days. In the preparation of the map great help was derived from the claim sheet of the Empire group, which was reduced to the scale of the map and plotted on the plane-table sheet. Elevations of each corner, all of which are clearly marked, were obtained from the original survey notes. With numerous base lines thus established it was a simple matter to spread the control by stadia readings and triangulation. The topography and geology were mapped simultaneously. Time did not permit the careful tracing out of all the contacts, so that on the map (Pl. VII, in pocket) formation boundaries located with reasonable care are shown by solid lines, whereas those projected or concealed are dotted.

TOPOGRAPHY.

The Alder Creek mining district comprises a segment of the northeastern slope of the rugged mountain area which separates Copper Basin from the main valley of Big Lost River. From Mackay, at an elevation of 5,888 feet, the surface rises southwestward, rather gently for 3 miles, but precipitously beyond, and finally leads to the summit of White Knob, a great mass of marble 9,600 feet above sea level. This knob is the principal landmark in the district and gave its name to the succession of companies so notorious in its history.

The general northeastward slope is trenched by many canyons and ravines, the chief of which are the fairly open canyon of Alder Creek, which traverses the southern end of the district, and the deep narrow canyon of Cliff Creek, which heads against White Knob and flows southeastward through the central portion, joining Big Lost River near Houston. This stream supplies water to the mines and smelter. North of Cliff Creek are several valleys which carry only flood waters. It is about the head of one of these valleys, shown in detail in Plate VII, that the principal mines are situated.

GENERAL GEOLOGY.

The rock formations of the district comprise a thick series of Carboniferous limestones, intruded by a batholithic mass of late Cretaceous or early Eocene granite porphyry, all traversed by narrow dikes of trachyte porphyry closely related to the granite porphyry in age and composition but differing from it markedly in general appearance. A thick series of Miocene lavas and tuffs occupies erosion depressions along the eastern and southern margins of the district. These volcanic rocks are partly covered by Quaternary gravels. In the higher parts of the district glacial deposits occur, but in no place visited are they conspicuous or extensive.

SEDIMENTARY ROCKS.

The sedimentary rocks of the district comprise a thick series of limestone beds which crop out as a V-shaped area with its point near the southeast corner of the district, and its wide end terminating against the alluvium-filled valley of Big Lost River, along the west half of the north border. In the eastern part of the district the limestones are concealed by the Tertiary eruptives and on the southwest they abut the granite porphyry along an exceptionally sinuous contact. In places large blocks of limestone occur within the area of the granite porphyry, the largest mapped being about 1,500 feet long by 500 feet wide. Eight distinct areas of this kind are indicated on the geologic map of a small part of the district (Pl. VII). One of them is 1,500 feet from the margin of the intrusion; the others are nearer.

The limestone series presents a monotonous succession of massive and semimassive blue limestone beds, rather pure above but carrying much chert in the lower members. In places the chert occurs as short, thick lenses, elsewhere as thin lenticular beds a few inches in thickness and 30 to 50 feet long, and yet again as beds of unmeasured extent, but from a few inches to several feet thick. This facies is well exposed along a zone through the Antelope and Hamilcar claims.

The limestone beds are sharply folded, and the dips are as a rule greater than 45°. The most common strike is N. 10°–20° W. and the dip is in general 50°–80° W. toward the igneous contact. Variations both in strike and dip are abundant and are so sharp that, though large faults within the limestone area were not recognized, their presence is not improbable.

In the absence of detailed sections it is only possible to give a rough estimate of the thickness of the limestone series present in the district. A hasty traverse of 4,500 feet down the ridge which extends north-northeast from the whim shaft revealed beds which, where exposed, dip 75°–85° W., thus suggesting a thickness of at least 4,000 feet. The position of these limestone beds in the general stratigraphic section of Idaho is more definite. Fossils found in their upper part are of upper Mississippian age, indicating that beneath these beds, unless cut out by the granite intrusion or by faulting, lie several thousand feet of limestones, shales, and quartzites, which separate them from the Algonkian schists, which in turn possibly have an equal thickness and are underlain by the Archean gneiss or its equivalent.

GRANITE PORPHYRY.

Granite porphyry crops out in the western portion of the area, represented by the special map (Pl. VII) and is part of a porphyritic intrusion which, as may be seen from Plate I (in pocket), appears at the surface over an irregular area of about 10 square miles, centering about White Knob. In most places this formation presents steep slopes, which terminate in high peaks, but locally along the margin it is even less resistant to erosion than the adjacent limestone. Thus in the vicinity of the mines the gentle slopes extending back a thousand feet or so from the contact offer some suggestion that the marginal facies is a separate intrusion. Other direct observations, however, make this view entirely untenable. The prevailing type of porphyry is well exposed along the upper canyon of Cliff Creek, especially in the vicinity of the old smelter site, where the rock is intricately jointed and beautifully sheeted.

The normal granite porphyry, as seen in the hand specimen, is a dark-gray rock that carries phenocrysts of feldspar from one-quarter to one-half inch in length and rounded crystals of quartz about one-quarter of an inch in diameter, which are set thickly in a granular groundmass composed of flecks of biotite and needles of hornblende along with much feldspar. As seen in thin section, orthoclase is the most abundant feldspar, though albite, microcline, and oligoclase, one or all, occur in most of the slides. Quartz is far less abundant than feldspar, but exceeds biotite in amount. Hornblende and diopside, though nowhere abundant, differ widely in amount from place to place. Titanite, magnetite, and apatite are generally present as accessories, and rutile is not uncommon. The quartz crystals are more uniformly and extensively embayed than in most of the porphyries which occur in east-central Idaho, and locally micropegmatite is exceptionally abundant.

Near the contact the rock in most places is essentially of the same composition as the main body, though here the groundmass is microcrystalline and the feldspar and quartz phenocrysts are much more widely spaced and are smaller. This type of rock merges by imperceptible textural gradations into the typical granite porphyry with which it agrees closely in composition. Contact effects clearly have been caused by both facies. The most notable metamorphism by the typical granite porphyry is the transformation of the great mass of blue limestone to white marble on White Knob and its local garnetization, and that by the finer-textured facies is the development of the garnet shoots in the Empire mine and the Copper Bullion tunnel.

The width of the zone of finer-textured rock differs greatly from place to place along the margin of the intrusion. In the vicinity of the Empire mine it is 2,000 feet wide, but in the canyon of Cliff Creek it is not more than 10 feet in width. It is narrow also where the granite porphyry extends beneath and surrounds the great marble mountain of White Knob.

None of the rock seen in place can be considered a typical granite, for all is distinctly porphyritic. Among the boulders along Cliff Creek, however, are some of equigranular texture, indicating that the granite porphyry has granitic facies as well as rhyolitic facies.

The granite porphyry cuts the Mississippian limestone beds, as is shown clearly by numerous exposures. The large irregular tongue shown in the northern part of the special map extends across the sedimentary formations almost at right angles to their strike. In the south wall of Cliff Creek the contact of the granite porphyry and the limestone is well exposed and indicates a slight crushing of the limestone by the magma. White Knob (Pl. XII, *B*, p. 56) is a mass of blue limestone metamorphosed by the granite porphyry to white marble, which is cut by many tongues of the intrusive rock and forms a most ragged contact with it. On the other hand, the granite porphyry forms peaks more than 9,500 feet high, an elevation approximately that of the old erosion surface, which is believed to have extended over this part of Idaho. It is concluded, therefore, that the invasion by the magma must have taken place before the close of the Eocene epoch, during which that surface was developed.

It is thought, however, that with a fair degree of certainty the age of the granite porphyry may be more closely fixed. We know definitely of only one period of granitic invasion in Idaho after the close of the Paleozoic era. This is represented in the main by the great batholith which crops out over a continuous area of more than 20,000 square miles in the central part of the State. Other smaller masses around the margins of this one have been considered outliers, which, if planation had proceeded to a sufficiently lower horizon, would be found to be continuous with the central mass.[1] The granite porphyry of Alder Creek district is believed to be one of these outliers and therefore essentially contemporaneous in age with the great central batholith of Idaho, which in the article above cited has been tentatively assigned to the late Cretaceous or early Eocene. The granite porphyry as described above includes the quartz porphyry and the granite of Kemp and Gunther,[2] who conclude that the granite is "the fundamental rock of the district" and that the quartz porphyry is a distinctly later intrusion. However, they make statements qualifying the definiteness of their conclusion.[3]

DIKE ROCKS.

Three periods of intrusion are represented by the dikes of the district. The oldest dikes correspond in mineral composition and texture to the marginal facies of the granite porphyry intrusion and in places may be traced as offshoots from that mass.

The youngest dikes, although similar to the older ones in composition, differ from them markedly in appearance. In these dikes large

[1] Umpleby, J. B., An old erosion surface in Idaho; its age and value as a datum plane: Jour. Geology, vol. 20, pp. 145-146, 1912.

[2] Kemp, J. F., and Gunther, C. G., The White Knob copper deposits, Mackay, Idaho: Am. Inst. Min. Eng. Trans., vol. 38, pp. 269-296, 1908.

[3] Idem, pp. 276, 296.

Carlsbad twins of orthoclase and locally medium-sized quartz and hornblende phenocrysts stud a dark-gray felsitic groundmass. Wherever exposed in mining this rock swells and disintegrates and usually requires immediate timbering to hold it back. On the surface these dikes are traceable in few places save in artificial exposures. In the discussion below the rock of these dikes is referred to as trachyte porphyry. Dikes of aplite, intermediate in age between the dikes of trachyte porphyry and of granite porphyry, were observed only in the vicinity of the big quarry and on the ridge northwest of the Copper Bullion tunnel. These dikes are entirely fresh below the immediate zone of surface weathering, although in the ridge mentioned they traverse an area of intensely metamorphosed limestone and near the big quarry one of them traverses garnet-magnetite rock formed from the granite porphyry.

TERTIARY ERUPTIVE ROCKS.

Eruptive rocks crop out over much of the eastern part of the district, where they occupy erosion depressions. They form part of a lava belt, consisting principally of andesites, latites, rhyolites, and related tuffs, which extends to the south and southeast. As is brought out in the general discussion (p. 35), they are thought to be of Miocene age. In this district no ore deposits have been found within them, although in Lava Creek and Era districts similar rocks inclose gold-silver and lead-silver veins.

ECONOMIC GEOLOGY.

ORE BODIES.

DISTRIBUTION AND PHYSICAL RELATIONS.

The metamorphic ore bodies of the district are exceptional in that most of them occur well within the igneous mass that caused the meta morphism. Great blocks of limestone, now in part transformed to garnet-magnetite rock, lie as much as 1,200 feet within the batholith, and about these some of the more important ore bodies occur. Others of the ore shoots seem to occupy the central portion of limestone blocks now almost completely transformed to lime silicate rock. At the time of the examination more than thirty fairly distinct ore bodies were being worked. These are widely distributed over the Empire group of claims in a manner that on first inspection seems to be without system. Careful observation, however, brings out two very persistent relations: (1) The margins of included limestone blocks are intensely mineralized in several places, particularly in the Copper Bullion workings; (2) the ore bodies for 400 feet above the Alberta tunnel are very definitely related to a fissure which strikes N. 20°–30° E. and dips 50°–60° SE. This fissure may be traced by a pronounced gouge wherever it traverses the granite porphyry, but within the areas of garnet rock it is not discernible in many places, and within many of the ore bodies it is entirely obliterated. In places later movement along the fault is shown by a smooth parting accompanied by a little selvage within the ore bodies. The Copper Bullion shoots are not related to any such dominant structural feature, but the solutions have clearly been directed by the joints in the granite porphyry.

CHARACTERISTICS OF THE ORE BODIES.

Three principal groups of ore shoots are recognized in the Empire deposits, one in the Copper Bullion and two above the Alberta tunnel. Each group is made up of branching arms, which commonly diverge upward but in places unite on higher levels. Most of the stopes are circular or elliptical in plan and range from a few inches to perhaps 30 feet in shortest diameter. The greatest known vertical extent of an ore body is from a few feet above tunnel No. 300 down to the 850-foot level. This shoot splits into three branches on the 500-foot level (the one shown in fig. 3, p. 46), another about 7 feet in diameter, and a third 7 by 14 feet in area. In the South Alberta shoot the large ore body opened near the tunnel level divides into east and west shoots a few feet above and these further split up with increasing elevation. In the Copper Bullion workings there are three groups of irregular stopes, one on the north side and two on the south side of the large slab of limestone that extends into the claim.

The Empire ore bodies are described in detail on pages 45–49.

ORES.

The ores of the Alder Creek district are valuable principally for the copper which they contain. Associated with the copper are small amounts of gold and silver. Lead deposits also have been recognized, but only a few tons of ore have been found in several hundred feet of development, In the following discussion only the ores of copper will be described and, as a matter of convenience in presentation, these will be classed as primary and secondary ores.

PRIMARY ORES.

The primary ores of copper comprise an intimate intergrowth of garnet and chalcopyrite along with subordinate amounts of pyroxene, pyrite, and pyrrhotite. The sulphides characteristically occupy interstices in the silicate minerals, though in a few of the thin sections and polished surfaces chalcopyrite and pyrite occur well within crystals of garnet. In the Copper Bullion ores, the principal source of sulphides at present, irregular bunches of chalcopyrite, a few of them 3 to 4 inches across, were observed embedded in garnet rock. Elsewhere in the same stopes lenses of irregular shape are inclosed in garnet rock and in one or two places appear to cut as veins across such rock. The characteristic occurrence of the chalcopyrite here, however, is as an interstitial filling between garnet crystals, the abundance of the chalcopyrite being such that the ore contains 5 to 6 per cent of copper to the ton. The north Alberta shoot above and below the tunnel level was, until the last few years, the chief source of sulphide ores in the district. Here also the interstitial distribution of chalcopyrite is well developed, but the ore is of lower grade than in the Copper Bullion shoots.

Analyses of the Alberta sulphide ores were not available, but an average of eight 50-ton lots of this type of ore, picked at random from the smelter returns on Copper Bullion ores, shows 35 per cent silica, 22 per cent iron, 5.73 per cent copper, and 0.073 ounce gold, and 2.18 ounces of silver to the ton. The maximum variations from these averages appear in the table on page 99.

The sulphides come in at different depths below the surface. In the north Alberta shoot sulphide ores appear at a depth of perhaps 200 feet, but in the south shoot oxidation is complete at the lowest level 700 feet below the surface. Some of the Copper Bullion stopes at a depth of 150 feet afforded sulphide ores; in others, extending to a greater depth, the ores were oxidized. As is discussed elsewhere (p. 67) all the workings are well above the bottom of near-by canyons, and the water which stands in undrained portions of the mine can not be considered as stagnant. In many places oxidation has been complete well below the level of such water, and where it has not its absence is believed to be due solely to local impermeability.

SECONDARY ORES.

Of the more than thirty ore bodies worked by lessees in 1912 all but two or three produced oxidized ores. The bodies were widely distributed over the claims of the Empire Copper Co., from the vicinity of the "big quarry" down through different levels to a depth of 700 feet in the Alberta tunnel; at depths of 50 to 250 feet in the Copper Bullion; and at several places near the surface between the 300-foot and the Copper Bullion tunnels.

The oxidized ore is characteristically a confused assemblage of variegated chrysocolla inclosing numerous blebs and wavy discontinuous bands of azurite and malachite and locally nodules of cuprite and ill-defined patches of copper-pitch ore. The heterogeneous arrangement of minerals appears even more pronounced in the thin section, when highly magnified. In many sections, predominantly of chrysocolla, it is impossible to find an area of it as large as the field of the microscope which is free from other minerals. The shades of chrysocolla grade into one another from brownish yellow through brown to brownish black. The color of the malachite ranges from bright-emerald to pale grass-green. In places it shows a delicate, silky fibrous structure or is banded in lighter and darker shades of green.

The study of the oxidized ores (as discussed on p. 68), brings out as their most striking feature the extremely meager segregation of material during their formation. The oxidation everywhere took place in the presence of silicate minerals, and it seems that colloidal silica wrapped up the other products before they migrated an appreciable distance.

MEAGERNESS OF SECONDARY SULPHIDES.

Secondary copper sulphides are exceedingly rare in the Mackay deposits. No zone of sulphide enrichment separates oxidized and primary ore. Chalcocite, the common mineral characterizing such zones in copper deposits, has been noted in only two or three hand specimens and no bodies of it have been found. Bornite and covellite, other secondary sulphide minerals, are but little more abundant than chalcocite. Both within ore shoots and hand specimens chrysocolla and garnet-chalcopyrite ores grade into one another. These facts, together with the evidence within the oxidized ore that but little migration of material accompanied its formation, leads to the economically valuable conclusion that no zone of secondary enrichment may be expected in the deposits. It does not follow, however, that the oxidized ore may not be of somewhat higher tenor than the primary ore. Most of the sulphur and much of the lime have been removed, and hence the percentage amounts of materials remaining should be greater. It is impossible to ascertain the probable amount of this increase from available data. The amount of sulphide ore shipped has been comparatively small but seems to indicate a somewhat lower content of copper than the oxidized ores, as shown by the following table of partial analyses. The analyses are of carload lots of approximately 50 tons each and were picked at random from the records of shipments in 1912. In addition to the average content for each constituent the highest and lowest determinations are given. The analyses constitute the basis of settlement with the Garfield smelter.

The table emphasizes the essential similarity between oxidized ores in different parts of the Empire mine and the general similarity between primary and secondary ores. Sulphur and lime are not recorded, but the absence of sulphides and the meagerness of sulphates and carbonates in the oxidized ore, together with the presence of veinlets of gypsum well out in the country rock, leads to the belief that these constituents have been leached in large part.

Average analyses of ore from Empire mine, Alder Creek district.

	Gold.	Silver.	Copper.	Iron.	Silica.	Part of mine.	Number of cars of 50 tons capacity.
Sulphide ore:	*Ounce.*	*Ounces.*	*Per cent.*	*Per cent.*	*Per cent.*		
Average	0.073	2.18	5.73	22.44	35.49	No. 3 stope, Copper Bullion	8
Highest	.110	2.70	6.75	27.80	44.80		
Lowest	.006	1.47	4.07	18.60	29.60		
Oxidized ore:							
Average	.034	2.85	7.17	25.36	31.28	No. 2 winze, Copper Bullion	5
Highest	.085	3.10	8.37	29.50	40.60		
Lowest	.006	2.00	4.82	22.10	23.50		
Average	.032	5.61	7.01	24.40	28.35	North Alberta shoot, 300-foot level	4
Highest	.041	7.30	9.24	45.20	35.00		
Lowest	.020	1.27	4.02	17.20	16.80		
Average	.044	1.88	5.51	15.90	45.67	North Alberta shoot, 500-foot level	4
Highest	.175	1.90	5.54	16.40	46.60		
Lowest	.035	1.80	5.45	15.40	44.10		
Average	.05	4.02	6.98	16.12	40.30	North Alberta shoot, 600-foot level	5
Highest	.055	4.50	7.83	17.20	43.00		
Lowest	.035	3.20	5.02	14.80	38.50		
Average	.029	2.88	6.70	19.30	38.58	South Alberta shoot, 50-foot level (Hunter lease).	14
Highest	.035	5.00	8.10	27.80	43.60		
Lowest	.025	1.40	4.26	14.90	30.70		
Hematite ore:[a]							
Average	.002	.57	1.15	54.91	12.11	Vicinity of Iron tunnel	7
Highest	.005	1.00	1.50	58.30	18.80		
Lowest	....	.10	.64	49.00	8.40		

[a] Included in table of ores because it represents a large tonnage of material valuable as flux.

INTERPRETATION AND CONCLUSIONS.

In the general discussion of the contact deposits (pp. 70–77) evidence is assembled which leads to the conclusions (1) that the garnetization took place after the solidification and jointing of at least the outer few hundred feet of the batholith; (2) that the marmarization, as on White Knob, probably occurred in part at the moment of intrusion; (3) that the metamorphism was a continuous process caused by solutions of gradually changing composition rather than an interrupted process caused by distinctly different solutions of different composition; and (4) that the great amounts of iron, silica, and alumina represent additions from the magma and can not be accounted for either by assuming a concentration of impurities in the original limestone inclusion or by leaching from the external limestone.

Practical conclusions of value in prospecting in the district are given on page 91.

MINES AND PRINCIPAL PROSPECTS.

The Alder Creek district contains only one extensively developed mine, the Empire Copper Co.'s property, which comprises 28 patented claims and several fractional claims and mill sites. Other near-by groups of claims are meagerly developed, and only the Grand Prize claim is patented, though the Champion group has been surveyed for patent.

EMPIRE MINE.

Situation and development.—The Empire group of claims lies on the steep mountain side 3½ miles southwest of Mackay, where the company's smelter is situated. The mine may be reached from Mackay either by wagon road or by a railroad owned by the Empire Copper Co. The railroad accomplishes the rise of 2,000 feet to the mine by a circuitous route 7¾ miles in length. It is equipped with two 23-ton Shay mountain-climbing locomotives and 38 cars.

Development at the mine comprises between 20,000 and 25,000 feet of underground work. (See Pl. VIII, in pocket.) There are four principal groups of workings—the Darlington shaft, the Alberta tunnel, the Copper Bullion tunnel, and the Cossack tunnel. Of these, the Darlington shaft, 700 feet deep, is no longer accessible, and the Cossack tunnel, now 1,900 feet long, is still 2,000 feet from a point beneath the north Alberta shoot. This tunnel enters the hill from the northeast at an elevation of about 6,760 feet. The Copper Bullion tunnel, situated at an elevation of 7,610 feet, is about 1,600 feet long, and its laterals, raises, and winzes total perhaps 800 feet more. The Alberta tunnel, at an elevation of 7,700 feet, which comprises a main adit 2,800 feet long connecting with the Darlington shaft, and laterals totaling about 3,000 feet, is the most important single piece of development. At 400 feet above it is tunnel No. 300, which is approximately 1,000 feet long. Directly above this tunnel, at an elevation 125 feet higher, is the North tunnel. Southward around the hill from the North tunnel at elevations between 8,200 and 8,400 feet are several tunnels, chief among which are the Davis, Hunter, South, Starlight, Sunlight, Iron, and Quarry tunnels, each representing from 100 to 900 feet of work.

The property is equipped with steam, gasoline, water, and air power, both at the mine and the smelter. There are three hoists and an 8-drill air compressor at the mine. An excellent machine shop is situated at the smelter. The smelter has two 125-ton blast furnaces 44 by 160 inches at the tuyères but is without converters.

History and production.—The history of the Empire mine is essentially the history of the Alder Creek district. Since its acquisition by the present company in 1907 it has been worked in part by the leasing system, and 30 to 40 leases are effective much of the time. The leases are let on ground of definitely specified dimensions for periods of one year and on the basis of a 20 per cent royalty. As the ore bodies are widely distributed, are of irregular shape, and range in size from small kidneys to shoots which yield hundreds of cars of ore, the system has proved more profitable than operation exclusively by the company. Its success, however, is due in a large measure to the spirit of justice in which it is administered and the resulting confidence of deserving lessees that if they lose money one year they will be given more favorable ground the next year. About half of the shipments have been of company ores, the lessees working on outlying portions of the deposits.

The production under the present management has been approximately $2,000,000 (to Dec. 31, 1913) from ores of about the composition shown by the analyses on page 99. Under previous managements it was about $500,000.

Geologic relations and ore bodies.—The ore shoots of the Empire mine and their geologic relations are described in the general section on the district (pp. 45–49). All the production has come from ground within the granite porphyry mass, where the shoots of ore are intimately associated with shoots of garnet rock. In 1912 and 1913 more than 30 separate ore bodies were worked, and within the history of the mine probably more than 100, many of them connected by stringers, have been productive. There are four general groups of ore shoots: (1) In the vicinity of the "big quarry" and Darlington shaft; (2) the south Alberta shoots, connected in part with group 1; (3) the north Alberta shoots; and (4) the Copper Bullion shoots. Many of the small tunnels between these major centers of mineralization, however, have exposed ore bodies not known to be connected with any of the others. The north and south Alberta groups of ore shoots have afforded most of the production, although recently large bodies of ore have been opened from the Copper Bullion tunnel.

GRAND PRIZE MINE.

The Grand Prize is a patented claim situated within the granite area east of the United States mineral monument No. 1. It is developed by a 90-foot shaft on a vein which strikes north. During the sinking of the shaft lead ore, containing 8 ounces of silver to the ton, afforded returns of about $10,000. The ore consisted of sand carbonate in a limonite gangue. In a south drift from the Darlington shaft the same vein was explored for a considerable distance and is said to have been 1½ to 2 feet wide and made up principally of argentiferous galena in a siderite gangue. Neither of the shafts were accessible at the time of visit.

CHAMPION GROUP.

The Champion group (fig. 13), comprising nine unpatented claims, is situated south-southeast from the Empire mine and south of Cliff Creek, at an elevation of about 8,000 feet. The first locations were made in 1901. The development includes three principal tunnels, Nos. 1, 2, and 3, in the central part of the property and several short tunnels near the north end.

This group of claims is of particular interest because it includes the most important deposits which have been found outside of the main granite porphyry mass. The development has been almost entirely within the limestone near its contact with the igneous rock. It may or may not be significant that the border zone of fine-grained porphyry is here only a few feet wide, whereas in the vicinity of the Empire mine it is locally 1,800 feet across. Garnet rock is developed in each of the two places where the immediate contact between limestone and porphyry has been explored. On the Crescent claim abundant magnetite and garnet rock bespeak intense metamorphism, but on the O. S. L. claim contact minerals are meagerly developed. The specimen of wollastonite shown in Plate XIII, *A* (p. 57), came from the Crescent claim. Dikes of trachyte porphyry traverse the limestone, the granite porphyry, and the secondary silicate rock.

Most of the recent development work has been done on tunnel No. 2, which is 144 feet lower than No. 1 and 185 feet higher than No. 3. It extends 476 feet almost due west, and throughout most of the distance traverses limestone beds which dip 50°–60° W. Near the portal is a dike of trachyte porphyry and within the last 100 feet is considerable fine-grained igneous rock, similar in appearance to the marginal phase of the granite porphyry. At a point 386 feet from the portal is a crushed zone of limestone which dips 60° W. It is about 30 feet wide, with gradational footwall and well-defined hanging wall. The material is heavily stained with iron and manganese and much of it has a jaspery appearance. The same zone is explored at a depth 50 feet lower. The lead ore occurs locally in this crushed zone, but no persistent body has been found. In tunnel No. 1 a similar crushed zone, perhaps the same one, also carries lead ore in places. A recent shipment from this level contained 20.3 per cent lead, 37 per cent insoluble material, 15.9 per cent iron, 5 per cent zinc, 0.7 per cent sulphur, and 6 ounces of silver to the ton.

OTHER MINES AND PROSPECTS.

Tiger group.—The Tiger group, comprising three unpatented claims, joins the Empire group on the north. It lies wholly within the granite porphyry mass but includes parts of three blocks of engulfed limestone. About the periphery of these blocks ore has been found in small amounts at several places. Several small tunnels, numerous shallow open cuts, and a shaft 35 feet deep comprise the only developments. In 1912 two cars of ore were shipped from the east end of the large limestone inclusion on the ridge north of the Copper Bullion tunnel. The ore consists mostly of copper silicate minerals similar to those in the Copper Bullion and Alberta shoots. Garnet rock surrounds the ore body, grading into granite porphyry on the one side and into limestone on the other.

The largest area of garnet rock on these claims occurs along the west side of the northern limestone inclusion and is only meagerly prospected. The type specimens of the new mineral custerite were collected along the transition zone between this garnet area and the limestone.

Horseshoe group.—The Horseshoe group, which comprises about 13 unpatented claims, lies north and east of the Tiger group. It is developed by a few open cuts and short tunnels and has made no production, though a few small lenses of lead ore in granite porphyry have been found.

Kennedy group.—The Kennedy group of claims is situated in the northwest corner of the area shown on Plate VII (in pocket). It com-

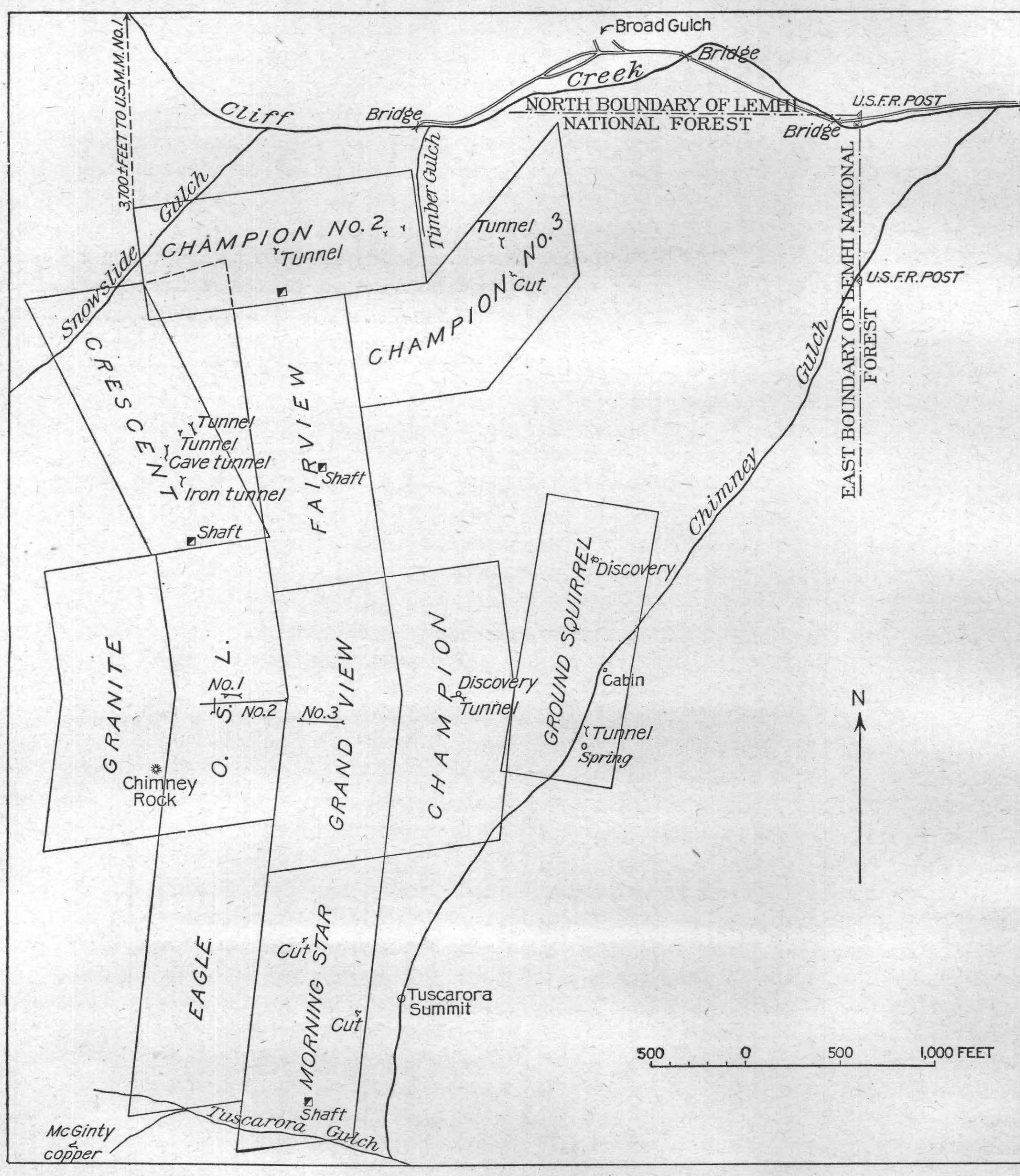


FIGURE 13.—Claim map of Champion group, Alder Creek district.

prises several unpatented claims, which lie mostly within the area of granite porphyry north of the Horseshoe group. Development includes two small tunnels not accessible at the time of visit. The property is held for both lead and copper ore but has afforded no shipments.

Easlie group.—The Easlie group includes the large limestone mass surrounded by granite porphyry near the north border of the area shown on Plate VII. It joins the Horseshoe group on the northeast. Several short tunnels, not accessible at the time of the examination, follow the east contact of the limestone, and on its west side near the summit of the ridge are a shaft and several pits. A small car of ore containing 30 per cent of lead and between 8 and 9 ounces of silver to the ton was obtained from pockets along the east contact of the limestone in 1909. No continuous ore body has been found.

COPPER BASIN DISTRICT.

SITUATION AND HISTORY.

Copper Basin is a broad intermontane depression, 7,000 feet above sea, situated at the head of East Fork of Big Lost River. It is about 10 miles long and 5 miles in average width. To the northeast rises the mountain range, which drops off abruptly within a distance of 10 miles to the broad valley in which Mackay is situated. To the east and south the basin is similarly bordered, but to the west it merges into a narrow valley, which drains it. An excellent wagon road follows the drainage of East Fork to its confluence with Big Lost River and thence down its valley to the railroad at Mackay, a total distance of 60 miles. Another road to Mackay, one only 18 miles long, leads across the summit and down Leman Creek. This road, however, is very steep in places and is used principally for light traffic. A road, scarcely passable, leads southeast from Copper Basin over the summit to Grouse.

The first mineral location in the district was probably the deposit of the Starr Hope mine, which was discovered and exploited during the decade following 1880. In October, 1888, the Reed & Davidson locations were made, on which work has been pursued intermittently up to the present. Three or four other discoveries date from about the same period. The total production of the district is about $100,000, half from the rich lead-silver ores of the Starr Hope mine and the remainder from the copper ores of the Reed & Davidson ($40,000) and adjoining claims. Most of the copper production has been from oxidized ores containing 5 to 6 per cent of copper and 10 to 12 ounces of silver and $3 in gold to the ton. A local smelter erected in 1900 for treating the oxidized copper ores was not a success, and it was soon decided that it was preferable to haul the ores to the railroad and ship them than to haul coke and sulphide ores into the basin and ship matte out.

GEOLOGIC RELATIONS.

The rock formations of the district include a thick series of sedimentary rocks, probably all of Paleozoic age, which during the late Cretaceous or early Eocene epoch were invaded by granite or quartz monzonite, which is now exposed in the southern part of the district, and which, because of the presence of metamorphic phenomena, probably lies not far beneath the surface in the southeastern part. Tertiary eruptive rocks, principally andesites, crop out as a narrow fringe along the south side of the basin and as a wide belt extending to the north and to the southeast. They occupy erosion valleys of an older topography. Copper Basin represents an unfilled segment of one of these valleys.

The sedimentary rocks in the southern part of the district comprise beds of metamorphosed bluish-gray fine-grained quartzite and dark-blue siliceous limestone. In the northern part are clear white fine-grained quartzite beds, which inclose others of black quartzite, and above them are beds of siliceous and calcareous shale and magnesian limestone. None of the beds are known to contain fossils, but from their lithologic similarity to strata elsewhere in the area of the general reconnaissance it is believed that they are principally of Paleozoic age. The metamorphosed rocks exposed in the southern part of the district may be pre-Cambrian, but their metamorphism is far less intense than the known pre-Cambrian of east-central Idaho, although somewhat more intense than is common to the Paleozoic rocks of the region. This fact, however, may be readily accounted for by the proximity of the granite rock. All these rocks are here grouped as of Paleozoic age.

The granitic rocks of the district were not studied in detail. One of the specimens examined microscopically is a fine-grained holocrystalline rock of medium gray color. It is made up of oligoclase, less orthoclase, some albite, quartz, hornblende, and biotite, and accessory magnetite, apatite, and zircon. The only other specimen examined is of closely similar appearance but does not contain plagioclase. Thus the rock seems to range in composition from a quartz monzonite to a granite, but which phase is predominant is not known. Boulders along Starr Hope Creek suggest that the dike rocks associated with the batholithic mass include granite porphyry and granite aplite and probably some diorite porphyry.

The Tertiary eruptive rocks are principally gray, purple, brown, and greenish-gray andesites, in which the phenocrysts and groundmass are about equal in area. Some of them contain biotite and others hornblende as the principal ferromagnesian mineral.

ORE DEPOSITS.

The ore deposits of the district comprise lead-silver veins and garnetiferous copper deposits, the copper deposits being closely associated with granite aplite dikes in the southeast side of the basin. The lead-silver veins occur near the head of Starr Hope Gulch in the southern part of the basin, and although the tunnels were not accessible at the time of visit the veins seem to be replacement deposits along a sheared or fissured zone in fine-grained quartzite. The Starr Hope mine explores the only known vein of this type in the district.

The copper deposits are of particular interest because of the garnet associated with them and the absence of any granitic rock exposed in the immediate vicinity. The presence of such rock beneath the deposits, however, is probable, both because of the development of garnet and diopside and because of the presence of dikes of granite aplite in association with the lime silicate rock. The deposits lie about 5 miles southwest of the granite porphyry batholith which caused the extensive metamorphism at Mackay, where the principal metamorphism occurred within the igneous mass itself and within the roof rocks. This fact further suggests that the granite underlies the Copper Basin deposits. The ores as now exposed are well oxidized and occur in tabular replacements in quartzite and calcareous shale and slate, both adjacent to aplite dikes and well removed from them. The dikes, all of which are narrow, presumably did not cause the metamorphism, for it seems impossible that they could have supplied the volume of material represented by the ores and the heat requisite for the garnetization. It is believed that they sprang from the source whence also sprang the metamorphosing solutions. Their relation to the ores is similar to the occurrence at the Empire mine.

The copper deposits are further described below under the heading Reed & Davidson group.

MINES AND PRINCIPAL PROSPECTS.

Reed & Davidson group.—The Reed & Davidson group of nine unpatented claims is situated in the southeastern part of Copper Basin. The claims were located in 1888 by the present owners, A. B. Reed and R. M. Davidson, of Mackay, Idaho, who have spent about $65,000 in developing them and have shipped from $40,000 to $45,000 worth of ore. A 30-ton smelter, formerly situated at Galena, in Blaine County, where it was built for the reduction of lead ores, was moved to the property in 1900 and made a short run in 1901. It did not prove to be a success, as shown by the abundant blebs of copper, some of them one-quarter of an inch in diameter, contained in the slag.

In the vicinity of the deposits the rock formations comprise clear white fine-grained quartzites, with a few interbedded layers of black quartzite, which grade upward into siliceous and calcareous shales and magnesian limestone. Dikes of granite aplite and granite porphyry traverse the sedimentary rocks along general northward-trending courses. The beds strike about N. 20° E. and dip 10°–30° SE. The ore bodies occur both adjacent to the dikes in the sedimentary rocks and along particular beds of the sedimentary rocks well removed from any known igneous rock.

Development includes five tunnels and a shaft 265 feet deep, in all perhaps 3,000 feet of work. The Parallel tunnel, situated near the base of the hill, comprises about 500 feet of work and reveals a body of ore 32 feet wide along the contact between granite aplite and quartzite. The ore clearly shows replacement phenomena against the quartzite, in that stringers of ore lead off along joint and bedding planes and open in places into bunches of ore of irregular shape and uneven size. The copper is largely in the form of amorphous chrysocolla, traversed by veinlets and including blebs and bunches of azurite and malachite. Associated with it is a great deal of magnetite and appreciable amounts of garnet and diopside. In places it seems that the aplite is diopsidized, but mine development is too meager and where exposed oxidation is too far advanced to warrant a definite statement. It is certain, however, that quartz similar in distribution to that in the aplite and a little orthoclase and albite occur in some of the diopside rock from points near the contact. The best grade of ore in the 32-foot crosscut occurs within 10 feet of the igneous rock. Shipments made from the entire 32 feet averaged, for a 50-ton car, 5½ per cent copper, 55 per cent iron, and 10 per cent insoluble matter and 11 ounces silver and $3 in gold to the ton. Above the Parallel tunnel is the 400-foot tunnel, where similar ore occurs as lenses 30 to 50 feet across in gently dipping calcareous shale.

Near the summit of the hill, at an elevation of 9,500 feet, is a shaft 265 feet deep; 120 feet of it is vertical and the rest inclined toward the east. The shaft starts in quartzite but soon passes into limestone traversed by a narrow dike probably of granite porphyry. The shaft was inaccessible at the time of visit, but it is said to represent about 900 feet of work and to have levels at 50, 100, and 180 feet below the collar. Ore was not found below the 180-foot level, where it occurred as a tabular body 6 feet wide along the contact between the limestone and a narrow granite porphyry (?) dike on the footwall. The ore from the 180-foot level, as seen on the dump, consists principally of copper carbonate intermixed with iron oxide, chrysocolla, and a little manganese oxide. The carbonate mineral is predominantly malachite, both of light pea-green and dark emerald-green color, the darker variety occurring as crusts on the lighter and the whole concentrically arranged. Associated with this material is a great deal of coarsely honeycombed gangue from which sulphides have been leached. The copper ore itself is very porous and vuggy, which further indicates that leaching has been extensive. It would seem therefore that even though copper ore has not been found below the 180-foot level it is to be expected.

Rosenkrans property.—The Rosenkrans property comprises six unpatented claims east of the Reed & Davidson group. The development includes four principal tunnels on two tabular deposits, from which a little ore was hauled to Mackay and one carload shipped from Ketchum. The ores are similar in every respect to those from the Reed & Davidson mine. They occur in slate and quartzite.

Anderson property.—The Anderson property comprises three unpatented claims which lie east of the south end of the Reed & Davidson group. The principal development is on a vein, from 6 inches to 2 feet in width, which has been explored to a depth of 100 feet. The ore, which as exposed on the dump is completely oxidized, is of excellent grade, averaging about 20 per cent copper and 30 ounces silver and $3.50 in gold to the ton.

Starr Hope mine.—The Starr Hope mine, situated in the extreme southwestern part of Copper Basin, is said to have produced $50,000 from rich lead-silver ores during the decade that ended about 1890. The ore was concentrated for shipment with two hand jigs. The workings comprise several short tunnels and one long one, possibly 1,500 feet of work in all, as estimated from the size of the dumps. The mine is situated near the head of a small gulch, which extends eastward from the southernmost tributary of Starr Hope Creek at a point about 2 miles above its mouth.

The rock formations in the vicinity of the mine comprise a series of rather intensely metamorphosed bluish-gray fine-grained quartzites and dark-blue siliceous limestones cut by dikes of granite and rhyolite porphyry. On the map the sedimentary rocks here exposed are grouped with the Paleozoic, although they are characterized by more advanced metamorphism and crumpling than any of the Paleozoic beds exposed elsewhere in the area covered by the reconnaissance. It is possible that further field studies will show them to be of Algonkian age. The igneous rocks, although not examined, are excellently exposed in the steep walls about the head of the canyon in which the mine is situated.

The ore, as seen on the dumps, consists of partly oxidized galena scattered irregularly through medium-grained bluish-white quartz. A little smithsonite and considerable iron oxide suggests the presence of sphalerite and pyrite in the primary ore. The workings were inaccessible at the time of visit, but from the composition of the dumps it is probable that the vein is inclosed in the fine-grained quartzite.

MULDOON DISTRICT.

By Elmer H. Finch.

GEOGRAPHY.

The Muldoon mining district is situated in the drainage basin of Little Wood River, in the extreme southwestern part of the Mackay region. It is approximately 24 miles almost east of Hailey, the county seat of Blaine County, and may be reached from that town by wagon road. The principal mining operations have been conducted at the Muldoon mine, near the former post office, Tustin, on East Fork of Muldoon Creek, approximately 3 miles by road northeast of the old town of Muldoon. At present little remains of the old town except kilns which were operated in connection with the smelter. The writer spent three days in the district in September, 1913.

The district comprises a high mountainous area, in which the differences in elevation amount to about 3,500 feet. The principal topographic features, as shown on the sketch map (fig. 14) of the district, are Muldoon Ridge (which forms the divide between Muldoon Creek and its east fork) and the great cirques that form the heads of the canyons which the ridge separates. The ridge is about 4 miles in length and very rugged. Rock slides many hundreds of feet in extent cover most of the surface of the northern part. The eastern slope is more precipitous than the western and is locally covered with small timber. The valley of East Fork of Muldoon Creek has been glaciated, although there is no well-defined cirque at its head.

MINING HISTORY.

The Muldoon mine has afforded the only important production from the district, although the Mutual mine was actively exploited for a few years. Both mines are now inactive and most of the workings are inaccessible. Among the prospects the Drummond claim, at the head of Copper Gulch, is being most actively developed at present. The statements regarding the early history of the deposits have been taken principally from reports on production of precious metals by the United States Bureau of the Mint.

The Muldoon mine lies immediately west of East Fork of Muldoon Creek, about halfway up the canyon and at the foot of Muldoon Ridge. The deposit was discovered in 1881 and within a few weeks the property was purchased from J. O. Swift & Co. for $50,000. The ledge as then exposed is said to have been 12 to 20 feet wide and to have contained 70 per cent lead. About 50 locations were soon made and later in the same year a smelter was erected. In 1882 the property was owned by the Little Wood River Mining & Smelting Co., which employed about 30 men in and about the mine. At that time there were nearly 1,400 feet of workings, all of which were reported to be in ore. There were two 40-ton smelters and a concentrating mill, which were first operated in the fall of 1882. They were operated also during the summer of 1883, and during that year produced about $34,500, most of which came from silver associated with the lead. A moderate production was made during each of a few years following and then production ceased and the mill and smelters were dismantled. In 1902 there was renewed activity in the district, but the extent of the development work on the Muldoon mine at that time is not known.

Again in 1907 an extensive plan of development was commenced in the district and was continued during 1908 and 1909, but with doubtful success. Shipping the concentrates necessitated a wagon haul of about 26 miles between Muldoon and Bellevue, and continuous shipping throughout the year was impossible because of the unsatisfactory condition of the road. Some of the shipping ore at that time was reported to run 42 per cent lead and 48 ounces silver to the ton, but the bulk of the ore was of milling grade. During 1910 several hundred tons of lead concentrates were shipped, but in December the company went into the hands of a receiver, and in 1911 the mine was practically idle. A new concentrating mill of 200 tons daily capacity was erected and operated intermittently during this period, the concentrates being shipped to Utah smelters. In all, this mine produced about $200,000, most of which came from the silver in the lead ores.

The management of the Muldoon property also made efforts to develop ore bodies in the Mutual mine but without success.

and are cut by numerous igneous dikes. The district apparently contains no extrusive rocks. The general strike of the formations along

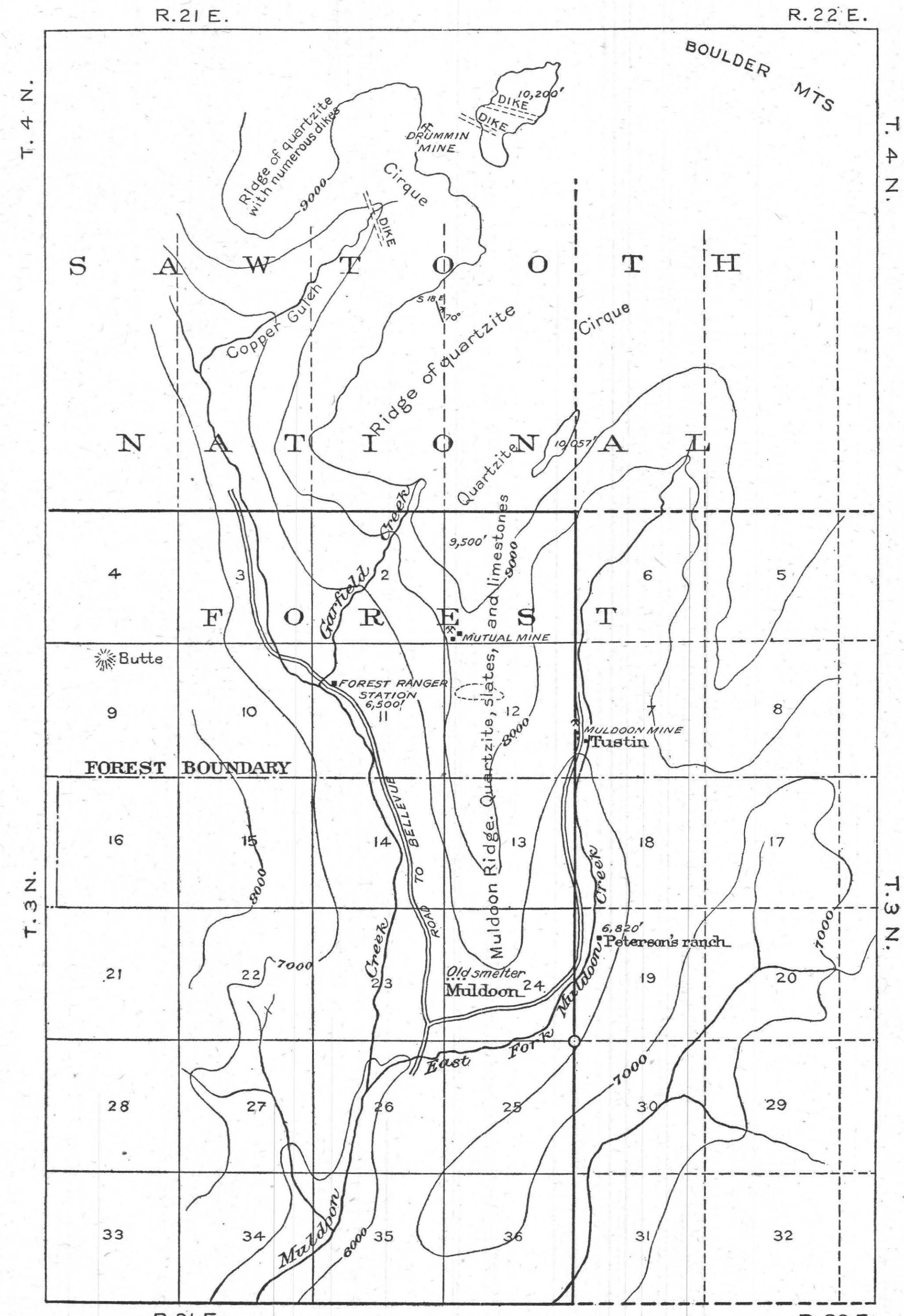


FIGURE 14.—Sketch map of Muldoon district.

GEOLOGY.

The rocks of the district are predominantly quartzite, with which are associated small amounts of limestones, slates, and sandstones, Muldoon Ridge, where an excellent stratigraphic section is exposed, and in the Muldoon mine is N. 8°–45° W.; the dip is generally from 23° to 40° NE.

SEDIMENTARY ROCKS.

From their lithologic similarity to the Wood River formation of Lindgren [1] the sedimentary rocks are believed to be, in part at least, of Carboniferous age. They are generally barren of fossils, although a few imperfect specimens were found which appear to be Carboniferous forms.

The quartzite exhibits a variety of shades of red, gray, and brown. In the cirque at the head of Copper Gulch there is considerable banded quartzite, in which many dark and light shades of blue alternate with bands of gray and brown.

The limestones are generally thick bedded and dark gray, although lighter gray shades are not uncommon. The quantity of slate present is relatively small, but one considerable zone is well characterized by films of graphite lying along the planes of bedding and slaty cleavage. The sandstone rocks, which are present in minor quantity, are generally quartzitic and of a brown shade on weathered surfaces. The unweathered and relatively unmetamorphosed sandstone rocks are light gray, but those which are more quartzitic are generally of a darker hue and their granular texture is not so apparent.

IGNEOUS ROCKS.

The dikes, which cut the sedimentary series at many points, are of several types, among them being quartz diorite porphyry (?), granite porphyry, and aplite. The dikes are most numerous at the head of Copper Gulch, in the northern part of the district. No large dikes were noted, but exposures of numerous small bodies are conspicuous. It was not practicable to trace the intrusions from point to point because they are largely obscured by the rock slides common on the ridge and slopes in the vicinity.

The quartz diorite porphyry (?) exposed on the ridge above the Muldoon mine is dark gray and carries closely spaced phenocrysts of feldspar and a small amount of biotite in a minutely crystalline groundmass. Microscopic study of a considerably altered specimen showed a holocrystalline groundmass in which there was abundant development of sericite after feldspars and chlorite after biotite, and a few grains of quartz. Some of the feldspars are oligoclase, and others seem to be orthoclase, although in the specimen studied they were too much altered to afford a definite determination.

The granite porphyry and aplite dikes are exposed in the vicinity of Copper Gulch. The granite porphyry dike is light gray, fine grained, porphyritic, and holocrystalline. It contains feldspar, largely sericitized, a smaller amount of quartz, and a still smaller amount of biotite, largely chloritized. The quartz is more abundant than it is in a normal granite, and micropegmatite is common in the specimen studied. Quartz and orthoclase of two generations seem to be present. There are at least two dikes of this type of rock near the head of the gulch. One of them is followed by the tunnel on the Drummond copper claim, but there the rock is more intensely altered than the specimen described, which was collected from an exposure about a mile to the southwest. There appear to be many aplite dikes in the vicinity of Copper Gulch. The constituent feldspar is considerably altered.

The intrusive rocks are clearly of post-Carboniferous age, but owing to the absence of strata of later age it is probable that no direct evidence affording a closer approximation of the age of the dikes will be found within the district.

There is clear evidence of contact metamorphism in the vicinity of Copper Gulch, where the indurated appearance of the extensive exposure of banded quartzite and the local presence of bands of lime silicate rock indicates that the rocks have been subjected to much more intense conditions of metamorphism than can reasonably be ascribed to the small dikes now exposed. These conditions rather point to a more important source of heat, probably an extensive underlying granitic mass of which the dikes are but apophyses. A large batholith crops out about 6 miles north of the mine, and it seems reasonable to believe that it extends beneath this area. This is considered (p. 33) to be contemporaneous with the great batholith of central Idaho, which is probably of late Cretaceous age. No evidence indicating the relative ages of the dikes was noted.

[1] Lindgren, Waldemar, U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, pp. 193–195, 1899.

ORE DEPOSITS.

The ores heretofore mined in the district are lead-silver, though a low-grade copper ore is being prospected at the Drummond claim in Copper Gulch.

The Muldoon mine has produced lead-silver ores, and no copper has yet been produced in the district. Although an attempt was made to develop lead-silver ores at the Mutual mine, no ore is believed to have been shipped from it.

LEAD-SILVER DEPOSITS.

The old stopes in the Muldoon mine were not accessible because of caves and water. In general, however, the lodes are conformable with the formation in strike and dip. The principal tunnels have been run on the contact between slate and quartzite, the slate usually above and the quartzite below.

Some of the low-grade ore, as seen in specimens picked from a bin at the fifth level, seems to have resulted from the alteration of an igneous rock, which is said to comprise the hanging wall of the vein throughout its extent. This dike crops out at the surface as a mass perhaps 100 feet wide and yielded the specimen of altered material identified doubtfully as quartz diorite porphyry.

This ore consists of a sericitized feldspar, galena, pyrite, quartz, and some zinc blende and chalcopyrite, together with a very small amount of iron oxide. Some low-grade ore from the seventh or lowest level contains minute crystals of pyrite and galena disseminated in altered quartzite.

It seems that replacement deposits in the dike and along the walls of slate and quartzite predominate in the ores, although some of the ore bodies may be fissure fillings. The effect or extent of the replacement of the quartzite and slate was not, however, possible of determination. The sericitization of the feldspars in the samples of ore collected at the fifth level is very apparent and indicates intense hydrothermal activity. In some of the thin sections galena and pyrite are clearly developed after the feldspar; in others the replacement, principally by pyrite, has taken place only in the greatly altered groundmass.

A further example of replacement processes is found in the low-grade ore from the lowest level. The country rock here is quartzite, through which the ore minerals are disseminated.

At the time of the examination water was standing several inches deep in the middle and lower levels of the mine and several feet deep in places where the tunnels were dammed by caved material. It was reported, however, that the upper workings were dry and that the first ore obtained was a carbonate of lead that carried 60 to 100 ounces of silver to the ton.

COPPER DEPOSITS.

The only copper deposit known in the district is on the Drummond claim at the head of Copper Gulch. The ore here occurs in a zone of contact metamorphism in which wollastonite and less diopside, garnet, and epidote have been developed in a calcareous rock which comprises part of a thick quartzite-limestone series. The hanging wall of the deposit is a dike of granite porphyry (?) approximately 15 feet wide, which is about the width of the irregularly mineralized zone.

The ore, which is of low grade, is a green fine-grained material consisting of patches and stringers of galena and anglesite, small crystals of copper sulphides, and patches of copper carbonate in a gangue of quartz and secondary lime silicates. Microscopic study shows the green epidote to comprise a mass of minute crystals with here and there a patch of calcite or a patch of galena intergrown with the epidote. The partial oxidation of the minerals is evident from the borders of anglesite around the crystals of galena. Although there is no water in the vicinity of the prospect, and the deposits are approximately 1,000 feet above the head of the small stream which flows in Copper Gulch, the ore is only very slightly oxidized. It is reported to contain 6 per cent copper and $5 to $6 a ton in gold.

MINES AND PROSPECTS.

Muldoon mine.—The principal development work in this mine has been done on 5 levels. The lowest level, No. 7, about 225 feet long, lies in quartzite which contains argentiferous galena, pyrite, and sphalerite. From the drift there are two crosscuts, each about 100 feet long, and from these several other crosscuts have been run into the country rock. Level No. 6, about 250 feet higher on the slope, is about 700 feet long in quartzite and black slate. About 400 feet from the mouth is a 400-foot crosscut to the south and a 200-foot crosscut to the north. The slate shows a considerable amount of graphite and small quartz veins. Neither level No. 7 nor level No. 6 produced any milling ore.

Level No. 5, about 70 feet higher, is on the contact of slate and quartzite for about 1,000 feet, and from this level there are several crosscuts, the longest being 100 feet, and one large stope, several sets wide, 50 feet long, and 200 feet high. This level, which was caved and partly filled with water near the entrance, is stated to have produced ore containing 50 to 60 per cent of lead and 45 ounces of silver to the ton.

Level No. 4, 60 feet higher, is driven 500 feet, although only accessible for about 200 feet, to the first stope, at the time of the examination. On each side of the tunnel there are small crosscuts. There are at least three large stopes on this level, which produced the best ore found in the mine, as well as the greatest quantity.

Level No. 3 is 500 feet long, and there are at least four stopes to the surface. All the ore has apparently been removed from the stopes, and none was found on the dump.

Level No. 2 is caved. Surface indications show the usual hanging wall of slate and footwall of quartzite. The ore has been stoped out to the surface.

Mutual mine.—The Mutual mine was inaccessible at the time the district was visited, and nothing is definitely known of the extent of the workings. It is not known to have shipped any ore.

Drummond copper claim.—The elevation of the Drummond prospect is about 9,000 feet. The tunnel runs N. 59° E. for 25 feet, beyond which it bears to the right 50 feet and intercepts the mineralized zone, which strikes N. 70° E. The ore is of low grade, and none has been shipped.

SKULL CANYON DISTRICT.

SITUATION AND HISTORY.

The Skull Canyon district comprises an area of about two townships situated in the extreme southeast corner of Lemhi County. It is reached by stage from Dubois, a town on the Butte branch of the Oregon Short Line Railroad, about 40 miles to the east. The stage road leads across the Snake River plains to the mouth of Birch Creek and thence up its broad valley to Kaufman, the local post office. The mail is brought in by stage three times each week. The old smelter town of Nicholia is 15 miles to the north.

Copper was discovered in the district about 1885, but not until 1904 were the lead-silver deposits recognized. The group of 18 patented claims belonging to the Weimer Copper Co. includes the known copper deposits of the district. They were exploited in 1906 and 1907 and a considerable amount of development work was done, the total ore shipped being worth $60,000 or $70,000. In 1907 this mine was closed and still remains idle. The Kaufman & Weaver group of claims, comprising the principal lead-silver property, is developed by about 2,300 feet of tunnels, drifts, and shafts, but only a little ore has been shipped from it. Another group of claims held for lead-silver has been located recently by F. G. Worthing, of Kaufman, but little development work has been done on it and no ore has been shipped.

GEOLOGY.

The district comprises a portion of the western slope of the spur of Beaverhead Range which extends south-southeast between the valleys of Birch and Medicine Lodge creeks. The surface rises within a distance of 4 miles from an elevation of 7,000 feet at the margin of Birch Creek valley through slopes, in most places grass covered, to the summit, which is 9,000 feet above sea level. Parts of the area are exceedingly rugged, although in general it is characterized by slopes much smoother than are common in this part of Idaho. Skull Canyon is a narrow gorge with almost vertical walls several hundred feet high, which at a point about a mile east of Kaufman open into the rolling highlands characteristic of the district. Other canyons indent the uplands north of Kaufman and a few of them reach the center of the range. In none of these canyons do streams persist throughout the year, although in the main valley Birch Creek affords water for irrigation and domestic use.

The rock formations of the district include limestone, magnesian limestone, and quartzite. The quartzite beds may be of Cambrian age and the magnesian limestones probably represent the Ordovician, Silurian, and perhaps the Devonian. It is possible that the massive limestones exposed in the walls of Skull Canyon near Kaufman are of Mississippian age. A cursory search failed to reveal fossils in any of the rocks. Perhaps the best section of the rocks exposed in the district occurs along Skull Canyon. For about a mile above the mouth of this canyon the walls are made up of massive beds of blue limestone, which dip 10°–50° E. At least 2,000 feet of this limestone is present, and neither the top nor the bottom is exposed. The age of the bed is not definitely known, although its massive character, great thickness, and general appearance suggests that it is the same formation that is exposed in Pass Creek canyon and described on page 27. Adjacent to this limestone formation on the east and separated from it by a fault is a quartzite series, perhaps 500 feet of which is exposed. The rock in most parts is fine grained, but at least one bed is conglomeratic, carrying rounded pebbles, the larger of which are 1 or 1½ inches in diameter. The pebbles comprise as much as 40 per cent of the rock, as shown by large blocks which occur in the talus slopes. Above the quartzite formation are thick beds of blue magnesian limestone, which contains numerous intercalated beds of light-gray to white material above the lower 500 feet. The thickness of this formation is not known, although it appears to continue eastward into the higher parts of the district, which were not visited. There also thin-bedded shales and limestones appear in some of the peaks.

No igneous rocks were seen in the district.

ORE DEPOSITS.

The ore deposits of the Skull Canyon district include lead-silver and copper deposits. The copper deposits occur about 2 miles east of Kaufman and the lead-silver 6 miles north of that town. The copper deposits have been most actively worked and have afforded most of the production. A considerable amount of development, however, has been done on the northern group of claims and a little ore has been shipped from them.

The two types of deposits have about the same geologic relations, both occurring in the magnesian limestone near its contact with the quartzite. They are described separately.

LEAD-SILVER DEPOSITS.

Kaufman & Weaver claims.—The principal lead-silver deposits occur on five unpatented claims known as the Kaufman & Weaver group, situated in the northern part of the district at an elevation between 8,000 and 9,000 feet. The deposits were located in 1904, but little work was done on them until two years later, when a company of Coeur d'Alene men secured an option on the group and did about 2,000 feet of work in an effort to find in depth the bodies of ore exposed in surface workings. No ore was found during the progress of this development, and, although conditions at several places offered encouragement to further search, work was discontinued because the option expired and could not be renewed.

Development consists of two shafts, about 300 feet apart, an 80-foot tunnel situated between them, and a 1,200-foot tunnel on a level 325 feet below the collar of the upper shaft and 100 feet below that of the lower shaft. There are numerous laterals from the main tunnel which total perhaps 800 feet in length.

Ore has been found only in the upper workings. The upper shaft is down 80 feet; the upper 30 feet is vertical and the lower 50 feet is on an incline of 35°. At the bottom of the vertical part is a 20-foot drift to the southeast along the vein, which also is followed by the incline. The ore body, which strikes N. 30° W. and dips 35° SW., is inclosed in magnesian limestone a few hundred feet east of its contact with the quartzite. The vein is about 4 feet in average width and is bordered by fairly definite walls. The ore is highly oxidized, for the most part loosely assembled lead carbonate, and is said to contain an average of 20 to 30 per cent lead and 2 to 4 ounces of silver to the ton. A shipment of 17,072 pounds of hand-sorted ore from this shaft contained 53.2 per cent lead, a trace of gold and zinc, 6.5 per cent iron, 3 per cent insoluble material, 3.5 per cent sulphur, and 7.1 ounces of silver to the ton.

The upper tunnel, situated about 100 feet N. 20° W. from the upper shaft, extends 80 feet in an earthy material stained with iron and manganese. At a distance of 30 feet from the portal a 30-inch vein of brecciated shaly limestone, cemented with galena, now largely altered to cerusite along with a little anglesite, crosses the tunnel on a course N. 38° E. It dips 65° NW., and is thus both in strike and dip almost at right angles to the vein exposed in the upper shaft. Neither does it agree in attitude with the inclosing magnesian limestone, which here strikes N. 45° E. and dips 30° NW.

The lower shaft, which connects with the lower tunnel and is about 100 feet deep, is 200 feet northwest of the upper tunnel. At a depth of 60 feet below the collar it crosses a vein of oxidized ore, irregular in outline, which seems to strike N. 30°–40° E. and to dip steeply to the northwest. It has not been explored on this level and was not found in the tunnel 40 feet below.

From the brief examination it appears that the three veins above described are separate and distinct, the two lower ones are parallel but 200 feet apart, and the upper one strikes almost at right angles to them. The lower tunnel was driven on a level 325 feet below the uppermost outcrop to explore these deposits at greater depth. This tunnel in most places is in greatly disturbed rocks, locally abounding in iron and manganese oxides, but at no place was a body of ore found. In general the tunnel follows the contact of the limestone and quartzite, which swings westward, but several laterals reach well toward the east into the area of magnesian limestone.

Worthing claims.—A large group of claims owned by F. G. Worthing, of Kaufman, extends around the hill to the southeast. Development on them consists of a few open cuts, pits, and short tunnels, in many of which a little lead ore has been found. No commercial deposits, however, have been discovered.

COPPER DEPOSITS.

Weimer copper mine.—The Weimer Copper Co., controlled by Jesse Knight, of Provo, Utah, owns 18 patented claims situated 2 miles east of Kaufman along the sides of Skull Canyon. The mine was worked actively for a period of 18 months prior to the fall of 1907, the ore being hauled to Dubois and thence shipped to the smelter. Since then it has laid idle.

Development consists of several quarries and tunnels on the northeast side of the canyon at an elevation of about 7,600 feet and of perhaps 2,500 feet of work in one principal tunnel and several minor ones on the southwest side of the canyon at an elevation of 7,600 feet, in all perhaps 4,000 or 5,000 feet of work. Buildings for housing 75 or 100 miners are situated on the property.

The ore bodies northeast of the canyon follow in general the bedding planes of the magnesian limestone; those to the southwest are veins in quartzite. The bodies in the limestone crop out along the canyon side about 200 feet above its bottom and dip into the hill at a low angle. The outcrop, which may be followed for several hundred feet, has been explored at several places by short tunnels and open cuts. The vein matter throughout is a heavily iron-stained jaspery material inclosing irregular lenses and slabs of limestone and large bunches of cherry-red hematite. The vein ranges in width from a few inches to 6 or 7 feet and locally splits into two or more veins or crosses along joints from one bedding plane to another a few feet away. Malachite is the most conspicuous mineral, although the gangue reacts for copper and doubtless contains considerable ferruginous chrysocolla. The characteristic occurrence of the malachite is in the form of incrustations along fractures, in beautiful needle crystals scattered through the finely vesicular portions of the vein, and in the small vugs which occur sparsely in the firmer parts.

The workings southwest of the canyon, in most parts inaccessible at the time of visit, develop a fissure deposit which courses east and west and dips steeply north. It traverses a greatly crushed white quartzite in which minute crystals of pyrite have been sparingly developed. The vein is said to be from 18 inches to 2 feet in average width, although in the present face of the lower tunnel it is 25 feet wide. The ore minerals consist of malachite, azurite, and chrysocolla, together with chalcopyrite and unimportant amounts of bornite, chalcocite, cuprite, copper pitch ore, and pyrite. Galena, together with secondary anglesite, cerusite, and a little wulfenite occurs in the vein as kidneys from 1 to 5 feet across but has not been found in sufficient amounts to afford a shipment of lead ore. The common gangue is a dark-brown jaspery material containing some copper. Irregularly scattered through it are bunches of barite which, though not abundant, are conspicuous because of their white color. (See Pl. XVII, *C*, p. 69.)

The most important type of ore is a jaspery-like material which should probably be called chrysocolla, although in most specimens it appears to contain more iron than copper. This may, however, be due to a mixture of iron-rich jasper and the copper silicate in particles too minute for identification in thin sections. Small specks of cuprite surrounded by narrow rims of copper pitch ore are not uncommon in the jaspery material, which varies in color from yellowish brown to dark reddish brown. Malachite occurs along fractures and as minute crystals lining vugs. Azurite is similar in occurrence but is rare.

The deposits of this district were formed during the earlier period of mineralization, discussed on pages 85–86.

CLYDE DISTRICT.

The Clyde district, which includes the northern part of what was formerly known as the Hamilton district, lies on the western slope of the Lemhi Range in the vicinity of Clyde. No definite boundaries for the district are recognized, but the name is here used to designate an area 20 miles long by 8 miles wide, in which Pyramid Peak is centrally situated. Clyde is about 35 miles northeast of Mackay, though the mail is brought in from Arco, 70 miles to the south.

Ore deposits were discovered in this district in the middle eighties and prospecting has continued intermittently ever since, though no large bodies of ore have been found and the total production has been very small. The entire development work probably does not exceed 2,000 feet.

There are two principal centers of prospecting, one in Basinger Canyon, northeast of Clyde, and the other in the canyon of Badger Creek, 9 miles southeast of Clyde. In Basinger Canyon copper-gold ores occur, and in the Badger Creek canyon lead-silver ores. Only the deposits in Basinger Canyon were visited. Here the Copper Bluff mine, situated at an elevation of 8,000 feet on the north side of the canyon, 1¼ miles from its mouth, is the principal property. The ores occur along the bedding planes of a massive blue magnesian limestone, which strikes N. 60° W. and dips 65° NE. The vein is locally as much as 18 inches wide, but in many places it narrows to a mere seam, which continues between the sharply defined walls. The development comprises an incline shaft, possibly 100 feet deep, and short drifts at three or four levels. The ore, as seen on the dump where 25 or 30 tons are stored, consists predominantly of chrysocolla, malachite, and azurite in a quartz gangue. A little gold is said to be present.

The country rock in the vicinity of the mine is magnesian limestone, which though it did not yield fossils at this locality is believed to be of Ordovician age. It overlies a massive fine-grained white quartzite, probably Cambrian, which toward the mouth of the canyon abuts the Algonkian schists and dark-gray quartzites, from which it is separated by a fault of large displacement. Other faults occur farther up the canyon.

These general geologic relations continue south along the range well beyond Badger Creek. The deposits in this locality have yielded some lead-silver ore, but no well-defined bodies of ore have been found and at present prospecting is inactive.

DOME DISTRICT.

SITUATION AND HISTORY.

The Dome mining district, situated in the northeast corner of Blaine County, Idaho, comprises the southern end of the region formerly known as the Hamilton mining district. It is reached by triweekly stage from Arco, a station on the Mackay branch of the Oregon Short Line Railroad, about 50 miles distant by the road commonly traveled. This road leads down the valley of Little Lost River to the Snake River plains, and thence along their margin to Arco, situated near the mouth of the valley of Big Lost River. A route about 15 miles shorter leads across the range of mountains that separates the valleys of Big Lost and Little Lost rivers, but this road has a steep grade and is used only by light traffic.

Lead-silver ores were discovered in the district about 1880, and during the following decade most of the deposits now recognized were worked. At that time the ore was hauled about 75 miles to the old smelter at Nicholia, near the head of Birch Creek. Only high-grade ores could be handled and from these possibly $75,000 was produced. Most of this output came from the Great Western group of claims, a property which has not been worked for many years.

The chief interest in the district at present centers in the Wilbert mine, formerly the

Daisy Black. This property was located in the early years of the district but made its first production about 1906, when two hand jigs were installed and a few shipments were made. In the fall of 1911 H. S. Knight, A. S. Ross, and associates, of Salt Lake city, purchased the property, organized the Wilbert Mining Co. (Ltd.), and immediately started the construction of a 100-ton concentrating mill, which made its first run in May, 1912. By July 20, 1912, the date of the examination, the mill had handled about 2,400 tons of ore and produced 300 tons of concentrates, which ran 51 to 53 per cent lead and about 9 ounces silver to the ton. The saving during this run was a little less than 70 per cent, or about 10 per cent below that estimated for the mill. By the end of the year the mill had produced approximately 1,500,000 pounds of lead and 10,000 ounces of silver.

During 1913, 18,223 tons, averaging 29 per cent lead and 2.8 ounces silver to the ton were milled, the average recovery for the year being 77.5 per cent and for the last six months 80.5 cent. This makes the total production 9,650,550 pounds of lead and 36,618 ounces of silver to the end of 1913.

TOPOGRAPHY.

The district comprises a segment of the western slope of the Lemhi Range, a high mountain mass which separates the valley of Little Lost River from that of Birch Creek. From the margin of the broad basin in which Little Lost River flows the slopes rise abruptly to 10,000 feet and higher in the central part of the range. In the northern part of the district Pass Creek, a tributary of Little Lost River and the only stream readily available for local power, has cut a deep canyon far into the mountains. A canyon comparable in size but containing only an intermittent stream extends eastward into the central part of the district. This canyon is shown on the map (Pl. XVIII, p. 80). About a mile farther south is still another large canyon, in which the Great Western group of claims is situated.

GEOLOGY.

ROCK FORMATIONS.

The rock formations exposed in the district are composed chiefly of quartzite, although interbedded with the quartzites is a distinct shale member and above them occurs massive beds of magnesian limestone. (See map, Pl. XVIII.) As now known the ore deposits occur wholly within the quartzite areas. Three distinct quartzite formations are indicated on the map, and for convenience they will be designated as upper, middle, and lower. Had time permitted it is probable that the upper quartzite could have been subdivided into at least three parts. Igneous rocks are not known to occur in the district.

The lower quartzite is the lowest formation exposed in the vicinity of the mines. It is a massive and semimassive white rock, which has a wide range in texture but in most places contains subangular pebbles of quartz, the largest of them one-quarter of an inch across, cemented by finer siliceous material. The total thickness of this formation is not known, although at least 200 feet of beds are exposed in the north side of the canyon below the Wilbert mine.

Immediately above the lower quartzite, but in many places owing to the structure apparently just beneath it, lies a shale formation possibly 150 feet in thickness. It has been crushed until the original bedding is almost obliterated, and in place of it schistosity is the characteristic feature. The rock is greenish gray and breaks readily into irregular plates, which commonly have curved surfaces. Its metamorphism was accompanied by considerable recrystallization, giving rise predominantly to chlorite and sericite.

Above the shale member is the middle quartzite, which as measured in the canyon above the Wilbert mill is 475 feet thick. This formation is readily recognized by its dark maroon color, which contrasts sharply with the prevalent light grays of the other quartzite formations. The lower part of it is made up of thick members, some of which are intricately cross-bedded, but in the upper part the layers are thin and regularly stratified.

The upper quartzite, the next younger formation, is 800 feet thick, although its full thickness is probably not exposed in the area studied. The lowest beds, beginning at the bottom, include 25 feet of milky-white fine-grained quartzite, overlain by 6 feet of dark-gray medium-grained quartzite, then 10 feet more of the milky-white variety, which grades into a brownish-gray facies in which numerous annelid borings are preserved, the total to this horizon representing a thickness of about 165 feet. If the upper quartzite were subdivided this portion would be the lower member. Above it comes 80 feet of thin-bedded clear-white fine-grained quartzite, which from local evidence might also be considered a distinct formation. Above this part comes 550 feet of massive beds of light-gray fine-grained quartzite.

Massive beds of magnesian limestone overlie the quartzite series, and, as they are well removed from the known deposits of ore, they were not examined carefully. This formation is unquestionably several hundred feet thick and is the predominant type near the center of the range east of Wilbert.

It is supposed that the quartzite beds are of Cambrian and the magnesian limestone of Ordovician age. (See p. 25.)

STRUCTURE.

The dominant structural features in the central part of the district are a number of normal faults which strike about N. 30° W. and an overturned fold along which thrust faulting has taken place. The thrust fault or faults have about the same strike as the normal faults, but the plane dips to the southwest instead of to the northeast. Both types of displacement have thrown younger beds on the northeast against older beds on the southwest. It is thought that the two types of faults represent distinct epochs of disturbance and that the folding and thrust faulting happened first.

The overturned fold may be perhaps most easily studied in the vicinity of the Wilbert mill. Here the shale is bounded on the west by the lower quartzite and on the east by the middle quartzite, rocks quite different in appearance. On the west the dip is easterly and on the east it is westerly. Exposures in the group of prospects along the road from the mill to the mine clearly show that the shale extends beneath the middle quartzite, and numerous exposures west of the mill indicate that the lower quartzite extends beneath the shale. The overturn has thus been from the southwest toward the northeast as shown in the section on Plate XVIII (p. 80). The fault along the northeast side of this fold was not adequately studied, but it seems to have a definite relation to the ore deposits. Indeed some of the ore bodies exposed on the lowest level of the Wilbert mine appear to lie along this fault. Northwest from the mine the fault may be traced with a fair degree of certainty well beyond the limits of the area mapped, but to the southeast it is not known to cross the canyon, although as there is generally little accompanying breccia it might readily be overlooked in this area of uniform rock.

The maximum displacement of this fault can not be more than a few hundred feet and may be less than 100 feet. The rocks in the footwall are not greatly disturbed, but those in the hanging wall are most intricately fractured, and it is in this fractured zone that many of the Wilbert ore bodies occur.

Four distinct normal faults of considerable extent are shown on the map. Two of these faults have dropped the dolomitic limestone against the upper quartzite, and the other two have appreciably offset the contact of the lower quartzite and the shale. The age relation of these displacements to the folding and thrust faulting is shown most clearly in the Wilbert mine, where the ore bodies which formed along the planes of thrust faulting and related fractures have been offset by many normal faults of minor throw.

ORE DEPOSITS.

There are four local centers of prospecting and mining in the Dome district, but of these only the Wilbert group of claims, formerly the Daisy Black, has been actively exploited in recent years. About 2 miles north of the Wilbert mine is the Johnson property, where 300 feet of development has been done on a number of small lead veins inclosed in magnesian limestone. Near these lead veins a zinc-bearing vein occurs but has apparently not been developed. The Great Western mine, situated about 1½ miles south of the Wilbert, has been developed by about 2,000 feet of tunnels, and early in the history of the district produced about $50,000 from silver-rich lead ores. It has not been worked for a number of years, and most of the old workings are said to be inaccessible. About 3½ miles south of this mine are the South Creek properties, from which a few small shipments have been made. Only the Wilbert and Johnson deposits were examined.

MINES AND PRINCIPAL PROSPECTS.

WILBERT MINE.

The Wilbert group consists of 13 claims, two of which are patented, and is developed by about 3,500 feet of tunnels, rises, and crosscuts. (See Pls. XVIII, p. 80, and XXI.)

Character of the deposits.—The ore here found occurs as veins, stringers, and disseminations in the fine-grained upper quartzite; much of the production comes from the disseminated lead-silver ores. The ore bodies on the upper levels are very erratic in size and distribution, although they are all related to a general zone of fracturing and are usually connected by stringers; on the lower levels they follow a thrust fault. The shoots commonly strike N. 20°–30° W. and dip either to the east or to the west at angles ranging from 20° to 80°.

The mine (Pl. III, *B*, p. 17) is opened on three levels with upper and lower intermediate levels between the two lower tunnels. (See Pl. XXI.) The uppermost ore body crops out a short distance above tunnel No. 1 and extends downward on a dip of about 60° SW. to a point 10 feet below level No. 2, where it is cut off by a flat, westward-dipping fault. All the ore bodies found between this fault and the lower intermediate level are nearly flat and of irregular shape but in the main dip eastward. On the lowest level, No. 3, a fairly distinct fissure has been followed for about 350 feet, along which are two ore shoots separated by about 75 feet of barren ground. The south shoot is 60 feet long and ranges in width from a few inches to 2 feet. The north shoot has been explored for 180 feet. The ore here is of excellent grade and occurs as a fairly distinct vein from a mere stringer to 3 feet in width, averaging perhaps 2 feet. Both shoots strike about N. 20° W. and dip 60° NE. The two shoots found on level No. 3 probably extend to the lower intermediate level, 55 feet above, where two shoots of similar ore have been found in normal relation to them.

Near the level of the lower intermediate tunnel the north and south shoots are joined by a long body of ore, about 7 feet wide and 6 to 20 feet in vertical extent, that rises toward the north in the plane of the vein at an angle of about 20°. At a point 160 feet north of the intersection of tunnel No. 3 with the main fault plane this ore body joins the north shoot, which continues northward for 270 feet and extends down to the level of the north drift from tunnel No. 3. Throughout the entire 270 feet this ore body averages 4 feet 2 inches in width, measured at intervals of 10 feet along the lowest level. In 1913 it produced 12,000 tons of ore averaging 30 to 35 per cent lead and 3 ounces of silver to the ton. An incline winze near this shoot indicates that the shoot retains its width and tenor to a depth of at least 70 feet below level No. 3, although development has not been sufficient to prove its length at this depth.

In this end of the mine the ore body instead of dipping 60° NE. dips 45° SW., which is in perfect accord with the general structure in the vicinity and is probably the dip throughout.

Relations of the ore deposits to the geologic structure.—An adequate account of the deposits would involve the consideration of many structural problems, but the short time allotted to the work in the district, only four days, made it impracticable to attempt even local detailed studies of structure. Certain broad relations, however, were worked out, which should be considered in the interpretation of local detailed observations. The Wilbert ore bodies occur along the zone of sharpest bending in an overturned anticline. The rocks here were greatly fractured during the development of the fold, and in some places, perhaps in most places, the formations along the crest of the fold broke and a thrust fault resulted. In the small gulch north of the Wilbert mine a fault of this kind is clearly shown, and in the mine itself several small ones have been identified.

After the compressional stresses which caused the folding were relieved the area was subjected to tensional stresses, which gave rise to the normal faults shown on the general map.

The ores were deposited along fractures developed during the epoch of folding, and in many places were offset during the epoch of normal faulting. The form of the ore bodies is therefore determined by the extreme irregularities of the earlier fractures, and their position is determined both by these fractures and by subsequent faults. In many places the later faulting has found expression along the earlier fracture planes, thus causing a brecciation of the ore where no offset is seen.

Ores.—The ore of the Dome district includes disseminated galena in quartzite and galena that occurs along a distinct fault plane, locally as a cement in the quartzite breccia which follows the fault.

The disseminated variety has a pepper-and-salt appearance due to dark specks of galena, now mostly altered to anglesite, scattered through the light-gray quartzite. (See Pl. XIX, *B*, p. 82.) In places this gives way to thin lenses and stringers of anglesite and galena. In the Wilbert mine the disseminated ore is characteristic of the flat bodies between tunnels No. 2 and No. 3, and the thin lenses and stringers occur extensively in the shoots developed on the lower intermediate level. The ore in the north shoot from level No. 3 is distinctly different in its occurrence, as it lies between fairly well defined walls along the plane of a thrust fault, in many places the galena being the cement of the quartzite breccia that accompanies the fault. The quartzite of this breccia is in many places not mineralized, a fact that seems strange in view of the exceptional extent to which galena has been deposited in the wall rock of the upper levels.

The mineralogy of the ore is simple, galena and its oxidation products, anglesite and cerusite, being the only abundant minerals. The galena occurs as the dense variety commonly known as steel galena, and its oxidation products are similarly fine grained. A few crystals of calamine were seen on level No. 3, suggesting the presence of sphalerite as a primary mineral, and here also a few copper stains and a little linarite (hydrous copper-lead sulphate) suggest the presence of some copper sulphide. But these minerals are certainly negligible in amount. Additional information concerning the ores is given on page 81.

The different ores found in the Wilbert mine are quite different in tenor, the disseminated ore containing from 12 to 20 per cent lead and the vein ore, made up of lenticular masses and stringers, from 20 to 35 per cent lead. During the month of December, 1912, when 50 tons a day was handled by the mill, the average tenor of the ore was 23 per cent, somewhat higher than that for previous months. During 1913, when most of the production was made, the average mill feed contained 29 per cent lead and 2.8 ounces of silver to the ton.

Abundant oxides of iron and manganese, which impregnate the wall rock for several feet away from the ore bodies, form a conspicuous and noteworthy feature of these deposits. (See p. 82; also Pl. XIX, *A*, p. 82.)

Ground-water level.—Ground-water level is well below the present lowest mine workings. The bottom of the canyon at the Wilbert mill is approximately 400 feet below the lowest level of the Wilbert mine and only about 1,000 feet away along the strike of the steeply dipping quartzite beds. The canyon at the mill is dry throughout most of the year, the stream which rises near its head sinking below the surface about 2 miles above the camp. Thus in the vicinity of the mines the elevation of ground-water level, though not susceptible of close determination from surface observations, is at least below the level of the bottom of the canyon at Wilbert.

JOHNSON PROSPECT.

The Johnson prospect, situated 2 miles northwest of the Wilbert mine, at an elevation of about 8,700 feet, lies entirely within the area of magnesian limestone. Development includes a tunnel, a small shaft 50 feet above it, and several short drifts, in all about 300 feet of work. Galena occurs at several places in the workings along slips and as bunches in the country rock, but no ore body of commercial extent has been recognized.

A vein of comparatively pure smithsonite crops out a short distance above the trail on a claim that joins the Johnson prospect on the east. It is exposed by a small pit only a few feet deep. The vein is about 14 inches wide and is inclosed in the magnesian limestone. The smithsonite is yellowish gray and has a rough botryoidal and drusy surface, but its distinguishing characteristic is its weight, which exceeds that of the adjacent limestone by about 50 per cent. The prospect seems to have been abandoned and certainly was never adequately developed, which suggests that perhaps in this district zinc ores have not been distinguished from the limestone formations.

GREAT WESTERN MINE.

The Great Western mine, situated about 1½ miles south of the Wilbert, was operated during the eighties for high-grade silver ores that occurred near the surface. It produced possibly $50,000 from ores containing about 130 ounces of silver to the ton. The property comprises five claims, the most important one of which is the Ingersoll. The ore bodies are said to be inclosed in quartzite similar to that at the Wilbert mine and are developed by about 2,000 feet of tunnel work now inaccessible. The mine was not visited during the reconnaissance.

SOUTH CREEK PROPERTIES.

The South Creek properties, most important among which are the Red Bird and the Dome claims, are situated about 5 miles south of the Wilbert mine, on the same slope of the range. They were not visited during the reconnaissance, but a few small shipments of ore have been made from them during the last 20 years. They are of particular interest, however, in emphasizing the wide distribution of mineralization in the district.

SUMMARY AND PRACTICAL CONCLUSIONS.

The principal points of interest in the Dome district and the practical conclusions which may be drawn from this paper are summarized below. (See also p. 91.)

1. The Wilbert deposits contain large bodies of plumbiferous quartzite, a type of lead ore which so far as the writer is aware is unique.

2. The mineralizing solutions caused noteworthy metasomatic alteration of the quartzite for 10 to 50 feet or more from the ore bodies by replacing the cement of the quartzite with some mineral or minerals which on breaking down gave limonite, pyrolusite, and probably calcite.

3. The loose sandiness of the plumbiferous quartzite is thought to be due to changes in volume, which accompany the alteration of galena to cerusite with anglesite as an intermediate form.

4. The Wilbert ore bodies were formed after the folding of the rocks of the district, but before they were displaced by normal faults. They present many structural problems, which should be considered in the light of these two epochs of disturbance, the one older than the deposits and the other younger, particularly because many of the later movements have taken place along the old fracture planes, which in a large part determined the sites of ore deposition.

5. Manganese oxide in this district appears to be invariably present in the wall rock adjacent to the lead-silver ores and hence may be considered an encouraging indication, both in prospecting and in mining. This statement, however, does not mean that manganese is everywhere accompanied by lead ore, but rather that lead ore appears to be everywhere accompanied by manganese.

6. The elevation of ground-water level in the district is not known definitely, but in the area shown on Plate XVIII (p. 80) it is certainly below the level of the bottom of the gulch, or at least 400 feet below tunnel No. 3 of the Wilbert mine.

BIRCH CREEK DISTRICT.

The Birch Creek district, which has produced about $50,000 from lead-silver ores, is situated 10 miles southeast of Kaufman, near the end of the range of mountains which separates the valleys of Birch and Blue creeks. The first mineral location here was made about 1885, when the deposits of the Birch Creek mine were discovered. This mine, the only one in the district, was relocated in 1888 by W. A. Scott, who sold it in 1908 to the Birch Creek Mining Co. Since then more than 30 cars of ore of 40 tons each, averaging 55 to 60 per cent lead and 4 to 10 ounces silver to the ton, have been shipped to smelters in Utah, the ore being hauled by wagons 36 miles to the railroad at Dubois.

The Birch Creek Mining Co.'s property consists of 10 unpatented claims situated among a group of low lava-capped hills on the north side of Birch Creek valley near its mouth. The development consists of a vertical shaft, from which levels have been extended at depths of 100, 125, 150, and 200 feet. A tunnel that enters from the southeast on a level 31 feet below the collar of the shaft connects with it at a point 106 feet below the surface by a winze and long incline. The principal stopes are north of the shaft, on the 100 and 125 foot levels.

The rock formations of the district consist of thin and thick beds of limestone and dolomite, which dip 20°–30° NE. They are cut by narrow dikes of basalt, which are contemporaneous in age with the lava flows of the district and of the near-by Snake River plains. One of these dikes, which stands almost vertical, may be seen in the sides of the shaft. It is about 4 feet wide and clearly cuts the vein.

The ore body dips northeastward, at a high angle in the upper workings, but it flattens below and follows the bedding of the inclosing rocks. The steeply dipping part is well exposed in the tunnel level, which follows a vein about 4 feet wide. To the northwest this vein is cut off by a breccia zone, which is explored by the winze and incline that lead to the shaft. Below this level, the 100-foot level, the prevailing occurrence of the ore is along the bedding planes, which dip approximately 20° NE. These flat-lying deposits average perhaps 18 inches in width, though the maximum is 6 feet. In them the better grade of ore occurs as small irregularly distributed bunches and lenses. At one place on the 100-foot level a shoot of this kind, 3 feet wide, has been followed for 100 feet and is said to average 10 per cent lead. Similar though smaller shoots, some of them averaging as high as 25 per cent lead, have been found elsewhere in the mine.

Galena, cerusite, and anglesite are the principal ore minerals. Above the 100-foot level lead carbonate is predominant in the ore, but below that level galena exceeds the other minerals in quantity. Throughout the deposit manganese and iron oxides are abundant, and in the upper levels a jasper-like substance comprises the principal gangue material. Wulfenite, though comparatively rare, is locally conspicuous, owing to its brilliant orange-red color. Smithsonite also is rare. The galena occurs both as the fine-grained variety known as steel galena and as coarse cubes.

A noteworthy feature of the deposits, which is particularly developed next to the main shoot on the 100-foot level, is a narrow border of recrystallized wall rock along the ore bodies. This border is made up of dolomite where the wall rock is rich in magnesium and of calcite where the wall rock is rather pure calcium carbonate. It ranges in width from a megascopically invisible margin to about 12 inches, the width apparently bearing no definite relation to the size of the adjacent ore body. Many little stringers of galena, which in places lead off into the wall rock or ramify local zones of breccia, are bordered by wider bands of these carbonates than are some of the large bodies of ore, and in places the carbonates are developed along fractures where no ore minerals occur. Locally galena is in sharp contact with unaltered phases of the inclosing rock. The outer borders of the carbonate bands are exceedingly irregular.

In places these carbonates bear every resemblance in form and distribution to the marmarized limestone near igneous contacts, and it seems only reasonable to interpret them as the result of comparably intense conditions of temperature and pressure. The ores themselves are in large part metasomatic replacement deposits, the material having been introduced, but the accompanying marginal band of carbonate is more reasonably explained as a simple recrystallization of material already present. Furthermore, as even narrow stringers of ore in many places are accompanied by such bands, their distribution suggests that the metamorphosing action was at least locally an advanced stage in the metasomatic replacement of the wall rock by the ore-bearing solutions.

ANTELOPE DISTRICT.

The Antelope mine, the only one in the Antelope district, is situated on Lead Belt Creek, a tributary of Antelope Creek, 6 miles south-southeast of Grouse post office, in Blaine County. The deposits were located about 1890, but not until 15 years later were they extensively developed. The first production from them was in 1908, when several shipments of silver-lead ore were made. Again in 1910 a little work was done and three carloads of ore were shipped, but the principal production was in 1913, when the output was 21 cars of 50 tons each, averaging 16 per cent lead and 16 ounces of silver to the ton.

The development includes about 2,000 feet of work, comprising a tunnel and shaft at an elevation of 7,150 feet on Lead Belt Creek and two small shafts and a tunnel 600 feet farther up the gulch. At the time of the writer's visit in 1912 the machinery and tracks had been removed and most of the workings were inaccessible.

The known ore bodies lie wholly in the limestone rocks which form the south side of the gulch along which the locations have been made. The north side of the gulch is composed of andesites and associated eruptive rocks. The ore bodies are said to occur as northward-trending veins which dip westward beneath the lavas. They crop out along the lower slopes of the valley side, and many of the older workings are above the outcrop. Present development, which is reported to be successful, is from a shaft in the valley floor. Near the surface the ores were richer in silver than at depth, some of the hand-sorted material averaging as much as 300 ounces to the ton.

ERA DISTRICT.

SITUATION AND HISTORY.

The Era mining district, which was active during a part of the decade that closed in 1890, comprises a portion of the mountain mass which borders the Snake River plains in eastern Blaine County. It is reached by road from Arco, situated 18 miles to the east. Lava Creek district joins it on the south and Antelope district is a short distance to the northwest. The area is now largely abandoned, most of the mines are caved and the annual production is negligible. During its period of activity, however, a 20-stamp mill and a roll mill of 10 tons capacity treated ore from five or six mines, producing in all perhaps $300,000 from oxidized silver ores. The larger mill has long been dismantled, and the site of Era, once a thriving settlement, is now marked only by old cellars and building foundations. The rise of the district was rapid, owing to the many discoveries of rich silver-bearing veins about 1885, and its decline was equally rapid, owing to their quite general impoverishment at a very shallow depth. The Hornsilver mine, by far the largest producer, was not worked at a profit below the 65-foot level, and the other deposits were similarly shallow.

TOPOGRAPHY AND GEOLOGY.

Only one day was spent in the district, so that the following notes are exceedingly fragmentary.

The district is drained by Era Creek, a small stream which leaves the highlands 3 miles below the camp and flows out on the Snake River plains, where in a short distance it disappears in the greatly fractured lavas which occupy that basin. The deep valley followed by the upper part of this stream extends northwestward for about 2 miles and then turns north-northeast and continues on this course to its head, an equal distance beyond. The principal mines, the Ella and the Hornsilver, are situated on the steep slopes near the head of this valley, and the Reliance and St. Louis mines are similarly situated in a short valley followed by Champaign Creek, a tributary which enters Era Creek from the west at a point about a mile below the Hornsilver and Ella mines. Southeast of the St. Louis mine on the opposite side of the main valley and about a mile south of the Hornsilver, are grouped the Policy, Little Jim, and Lost Chance properties. Elevations in the area range from 5,300 feet in the eastern part to perhaps 8,000 feet along the higher divides.

The district, which as locally defined is about 6 square miles in extent, lies wholly within an area of eruptive rocks and related tuffs, possibly cut by intrusions of similar composition. The lavas include rhyolites, andesites, and possibly latites, which form a part of a broad belt of eruptive rocks that extends to the northwest for many miles and rests in different places on the late Cretaceous granite and Paleozoic sedimentary rocks. Timber Mountain, on the northeast margin of the district, is a high prominence around which the lavas rose to an elevation of about 7,500 feet. On the west their contact with the older rocks follows the ridge that separates the valleys of Era and South Fork of Antelope Creek to a point west of the St. Louis mine, where it gradually swings westward and crosses the valley of South Fork of Antelope Creek. Southeastward the eruptive rocks which predominate in the district are flanked by the basalt flows of the Snake River plains. In general these rocks do not extend above an elevation of 5,500 feet, but locally dikes traverse the higher slopes and are clearly the feeders of small flows, remarkable in their fresh appearance, which lie as patches on some of the slopes in the southeastern part of the district.

The rocks of the central area comprise rhyolite, andesite, and related tuffs, the relative abundance of which is not known. A specimen from the St. Louis mine, though intensely altered and tentatively classified as rhyolite, may from its general appearance and porphyritic texture be a quartz diorite porphyry. The tuffs, though widely distributed in the areas, do not occur in nearly as great quantities as the lava rocks. The prevailing rocks of the district are believed to be of Miocene age. (See p. 35.)

ORE DEPOSITS.

The ore deposits of the district belong to that group of late Tertiary veins which is fairly well characterized collectively by cryptocrystalline quartz and chalcedony, crustified structure, sericitization of the wall rock, predominance of the precious metals, and association with Tertiary lavas. Here, however, the base metals are abundant, argentiferous galena being the chief ore mineral in some of the veins.

The veins in general strike north and dip either to the east or to the west. They range in width from mere stringers to 5 feet or more, but have not been found to extend more than about 100 feet below the surface, though in only the Hornsilver vein has exploration been extended to levels greater than this.

The metallic minerals noted during the hasty examination are galena, sphalerite, wurtzite, chalcopyrite, proustite, tetrahedrite, argentite, cerargyrite, smithsonite, and cerusite, the last three of which are clearly of secondary origin and the others primary, at least in most places. Of these minerals pyrite, galena, sphalerite, and wurtzite occur in the walls, the first in most places, the others locally, as replacements of the minerals of the inclosing lavas and tuffs. The prevalent gangue minerals are cryptocrystalline quartz and chalcedony, though in some of the deposits calcite is abundant, and locally barite occurs.

A characteristic feature of the deposits is the intense sericitization of the inclosing rocks and the development in them of pyrite, galena, wurtzite, sphalerite, and sericite, a feature described on pages 87–89.

MINES AND PROSPECTS.

Ella mine.—The Ella mine, located about 25 years ago, is situated near the head of Era Canyon at an elevation of 6,000 feet. The development comprises approximately 1,000 feet of work in one long tunnel and several short ones. The principal tunnel was inaccessible at the time of the writer's visit, and those farther up the slope were not examined. The ore is said to occur in a 4-foot vein, which dips 35° W. and is inclosed between poorly defined walls of an intensely silicified lava, probably andesite. A specimen of this rock from the dump contains a great deal of secondary silica, developed both in the groundmass and after the phenocrysts, few of which could be identified. Sericite in minute flecks and felted aggregates has been formed largely after the feldspars. Also of later origin than the inclosing material is pyrite, which occurs as minute cubes and grains scattered irregularly through the rock and as films along fracture planes.

The ore, which is said to contain 8 per cent lead, 5 to 10 per cent zinc, and 12 ounces of silver to the ton, consists principally of galena, sphalerite, and pyrite in a quartz gangue which includes many fragments of wall rock. Argentite, proustite, cerargyrite, tetrahedrite, smithsonite, and cerusite also are present in the ore on the dump, but these minerals appear to be very subordinate in amount to those first named.

The ores have been concentrated for shipping both by hand jigs and by a mill of 10 tons daily capacity, which is fitted with rolls and a Wilfley table. It is said that 10,000 tons of ore have been treated.

Hornsilver mine.—The Hornsilver mine, situated at an elevation of 6,200 feet near the head of Era Canyon, is the oldest mine in the district. It was located about 1885 and during the following three or four years was actively worked, the ore being treated in a 20-stamp mill, long since dismantled, situated 3 miles below the mine. No record of the production is available, but it is claimed locally that during this period approximately $250,000 was derived from rich silver ores. Nearly all the ore came from depths within 65 feet of the surface, although a shaft was sunk to a depth of 285 feet and extensive prospecting done on the lower levels. In all, the development comprises perhaps 3,000 feet of work.

The workings have been long abandoned and were entirely inaccessible at the time of visit. No ore appears on the dumps, but it is said that cerargyrite, included in a heavily iron stained quartz, was the principal ore mineral. The deposit is well within the area of eruptive igneous rocks.

St. Louis mine.—The St. Louis mine is situated on the south side of Champaign Gulch. The property consists of one unpatented claim and is developed by three principal tunnels, two from the east and one from the south, in all perhaps 1,500 feet of work. Possibly $15,000 worth of ore has been shipped from the mine. The ore occurs in small irregular lenses and bunches, from 6 to 15 inches wide, in a vein which strikes N. 5° W. and dips 50° SW. The footwall rock is a thin-bedded water-laid tuff, which strikes north and dips 30° E., and the hanging wall is a dull-gray porphyritic rock, probably a rhyolite. Both the rhyolite and the tuff are intensely metamorphosed, sericite, quartz, and pyrite being extensively developed. The tuff was made up originally of small angular and subangular fragments now defined by narrow bands of iron oxide along the borders of the grains. The grains themselves are made up of minute, diversely oriented grains of quartz. Much pyrite and a little galena occur as isolated crystals, grains, and clusters of grains in the wall rock. Sericite, though not abundant, is irregularly scattered through the only slide studied. The specimen from the opposite wall contains much sericite and numerous grains of pyrite, along with distinct phenocrysts of quartz. None of the feldspars in the specimen studied are determinable, so that the tentative classification of the rock as rhyolite is based entirely on its general appearance and the presence of quartz phenocrysts.

Replacement of the rhyolite has been an important process in the formation of these ore bodies. In many places the gradation is striking between wall rock and ore made up entirely of galena, sphalerite, and wurtzite, and small amounts of pyrite. (See also p. 87.)

The ore is made up almost entirely of argentiferous galena, sphalerite, pyrite, and a little wurtzite in a quartz-chalcedony gangue. Much of the galena along the central zone occurs in distinct cubes and cubo-octahedrons. The wurtzite, and in most places the sphalerite, is fine-grained and without crystal boundaries, but locally the sphalerite occurs in peculiar spherical masses commonly one-fourth to one-half inch in diameter. These are further described on page 88.

Reliance mine.—The Reliance group comprises four unpatented claims developed by a 300-foot tunnel situated at an elevation of 6,500 feet in a small gulch tributary to Champaign Canyon near its head. The inclosing formation is a light-gray porphyritic rock in which feldspar and quartz crystals stud rather thickly a very fine grained groundmass. Thin sections studied under high magnification show sericite to have developed after all the minerals except quartz. Quartz is present as large phenocrysts and as minute grains abundantly scattered through the groundmass, the minute grains being probably largely of secondary origin. Pyrite also has been abundantly developed and is conspicuous both megascopically and microscopically. It occurs as cubes, irregular grains, and clusters of grains, replacing all the minerals of the rock except quartz, although most abundant in the groundmass.

The ore occurs as stringers either along the hanging wall or the footwall of a 4-foot ledge, made up largely of crushed rock, which strikes north and dips east at a high angle. The minerals noted are pyrite, jamesonite (?), galena, sphalerite, and chalcopyrite, irregularly distributed through a fine-textured quartz chalcedony gangue. No ore had been shipped from the property, although a carload was in the bins at the time of visit.

Other mines and prospects.—Several claims are situated on the southeast side of Era Canyon, near the old town of Era. The chief among them are the Policy, Little Jim, and Last Chance properties, none of which were visited.

The Policy mine was worked in conjunction with the Hornsilver and is said to have produced a few thousand dollars from ores containing 8 to 24 ounces silver and $2 to $5 in gold to the ton. The development consists of about 250 feet of work along a 4-foot siliceous vein which strikes north. Specimens from the mine contain considerable barite intergrown with the iron-stained cryptocrystalline quartz and chalcedony of the gangue.

The Little Jim is situated just south of the Policy and a short distance east of it is the Last Chance. Neither of these properties is extensively developed and their production is negligible.

LAVA CREEK DISTRICT.

General features.—The Lava Creek district is named from the black vesicular basalt flows which represent the last eruptions on the Snake River plains and extend well into the area, resting on many of its upper slopes as a thin and patchy veneer. Along the canyon of Lava Creek, the principal drainage line of the district, these patches coalesce, and the bright black and in many places ropy lava rock covers the valley floor. The district is about 20 miles west of Arco and joins the Era district on the southwest. It may be reached twice weekly by stage from Arco, a station on the Mackay branch of the Oregon Short Line Railroad. Martin, situated near the mouth of Lava Creek valley, is the local post office.

Although there is one rather extensively developed mine, the district has not produced heavily, only $90,000 being claimed. About half of this amount came from ores hauled to the Nicholia smelter during a few years following 1885, and the remainder from scattered shipments during the last 20 years.

The district comprises a segment of the mountain mass which in this general region borders the Snake River plains on the north. Lava Creek, a short eastward-flowing stream, the waters of which sink soon after reaching the plains, is the main drainage line of the area and in many places flows on a surface of weathered basalt. Beneath these comparatively recent lavas lies the series of eruptive rocks and tuffs so extensively developed in the Era district to the north. Rocks of Paleozoic age form the higher mountains in the western part of the district, where they are separated from the lavas by an irregular erosional unconformity.

The known ore deposits occur within the area of older eruptive rocks and associated tuffs.

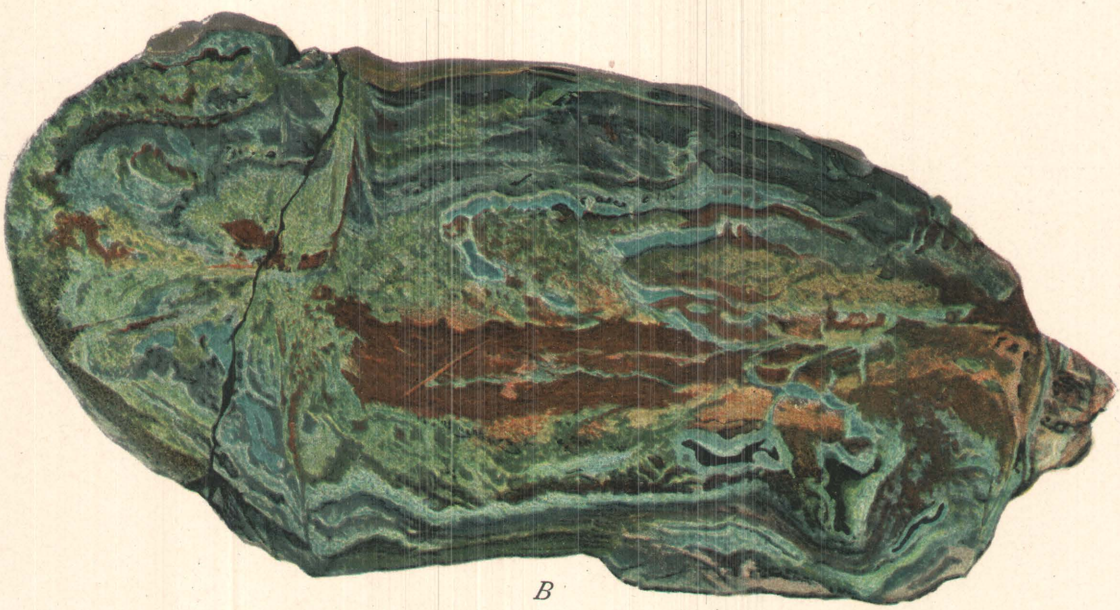
Tungsten-bearing veins recently discovered near the head of Lava Creek are described on page 85.

Hub mine.—Besides the Hub mine, situated at an elevation of 6,200 feet on Lava Creek, about 2 miles southwest of Martin, there are several prospects in the district, but none of them were visited. The development at the Hub mine comprises a tunnel 1,500 or 2,000 feet long and, 200 yards farther up the valley, a shaft, which, with its drifts (as estimated by the size of the dump), possibly represents an equal amount of work. The tunnel extends north for several hundred feet and then turns westward along a zone of movement which strikes N. 80° W. This zone is about 30 feet wide and dips steeply northward. It is bordered on the south by a compact greenish-gray tuff, which is rather poorly stratified but ranges in texture from grains the size of rice to those which may only be seen with the aid of the microscope. The north wall, at least in part, is a porphyritic rock characterized by the phenocrystic development of feldspar (probably orthoclase) and hornblende. Both rocks are so intensely metamorphosed that their original nature can be more closely determined from the hand specimen than from the thin section studied under the microscope. In each rock sericite and calcite are very abundant, as is also silica. Pyrite, as small bright cubes and patches readily seen with the unaided eye, is scattered through both types of rock but appears to be more abundant in that on the hanging-wall side.

The ore occurs as stringers, lenses, and blebs in the zone of breccia above described. The most abundant minerals are pyrite, galena, proustite, and stephanite in a calcite-quartz gangue. In places the galena has clearly replaced the brecciated material, but elsewhere it seems to have occupied open fractures. The silver minerals occur as minute crystals embedded in the gangue material and intergrown with the pyrite, and also as narrow veinlets cutting across the sulphide ore. The ore from this tunnel, the only accessible part of the mine, is said to contain 4 per cent lead and 100 ounces of silver to the ton.

The deposits though given but a very cursory examination, clearly belong to the group of late Tertiary veins described on page 86.

A



B

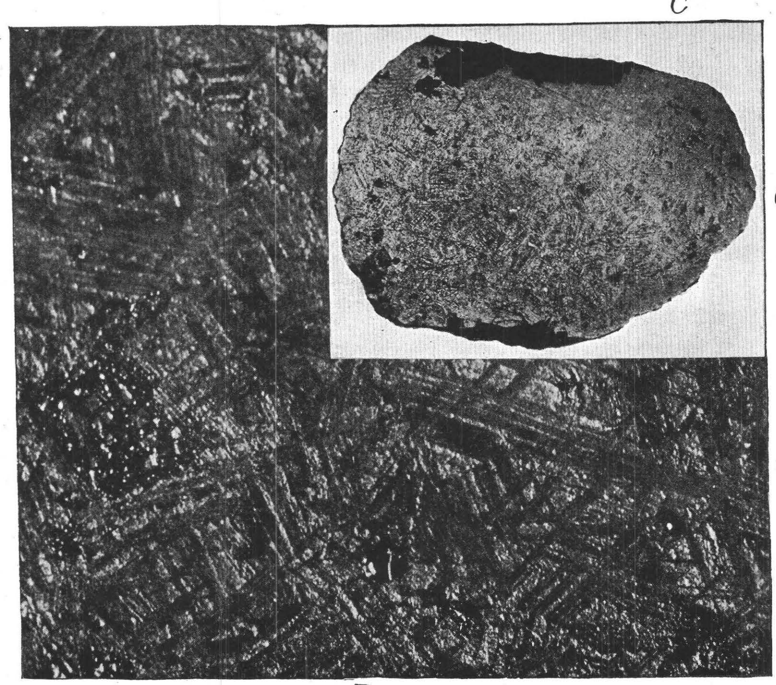
A. HOEN & CO. LITH. BALTIMORE

TYPICAL SPECIMENS OF ORE FROM EMPIRE MINE.
(*A*) "CHRYSOCOLLA" ORE. (*B*) CARBONATE COPPER ORE.

A

B

C



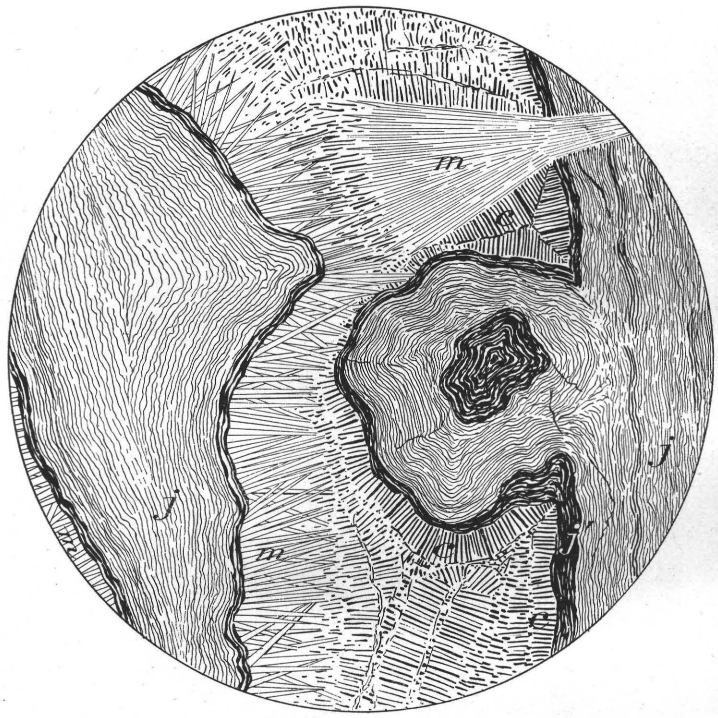
a

b

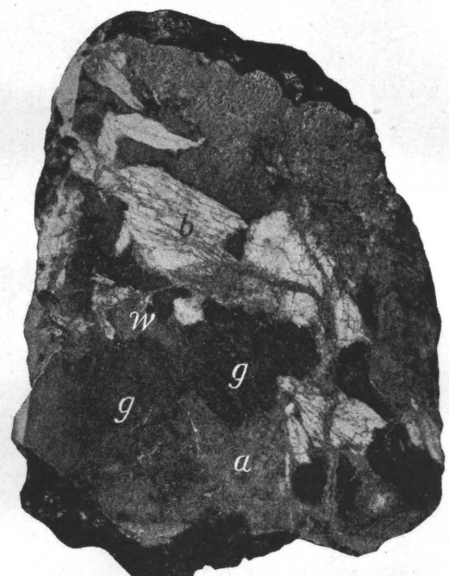
D

SPECIMENS OF ORE FROM EMPIRE MINE, ALDER CREEK DISTRICT, IDAHO.

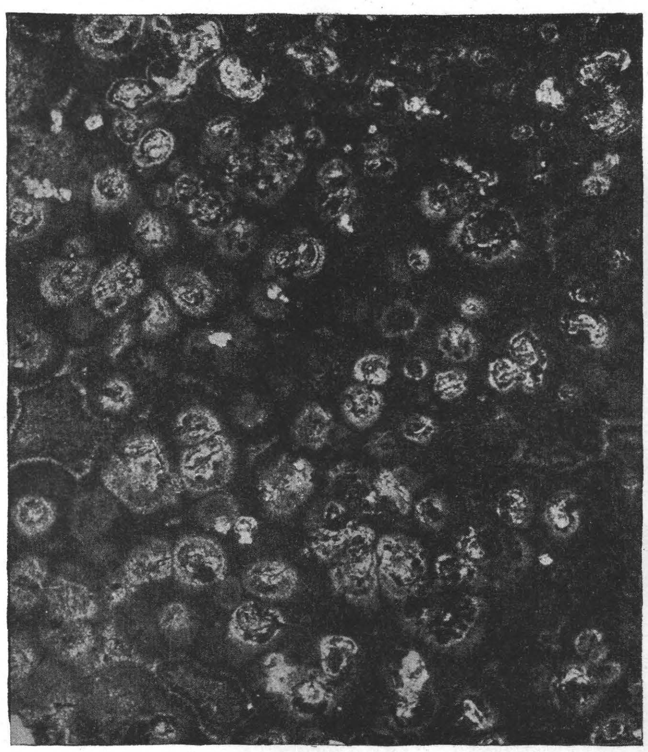
A. Intimate association of malachite (light) with brochantite cut by veinlets of gypsum, from Copper Bullion tunnel. Natural size.
B. Garnet and chalcopyrite (light specks) ore traversed by a veinlet of gypsum, from Copper Bullion tunnel. Natural size.
C. Cuprite (light) including specks of native copper, surrounded by a layer of tenorite in chrysocolla ore, from 300-foot level.
D. Covellite pseudomorphous after chalcopyrite (black areas and lines), from 300-foot level. *a*, Natural size; *b*, × 30.



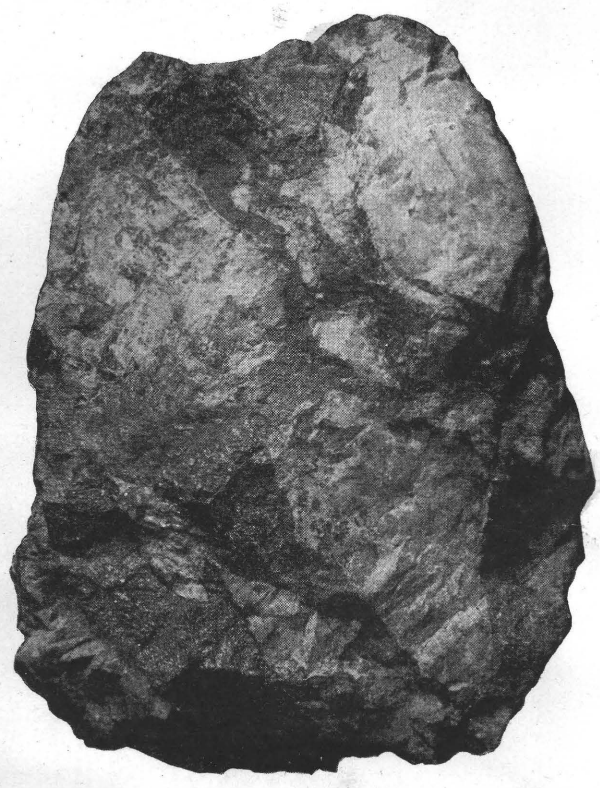
A



C



B



D

A. DIFFUSION PHENOMENA IN CHRYSOCOLLA ORE, EMPIRE MINE, ALDER CREEK DISTRICT, IDAHO.

Malachite, *m;* crystallized chrysocolla, *c;* and ferruginous amorphous chrysocolla, *j* and *j'*. Camera lucida drawing. × 270.

B. DIFFUSION PHENOMENA IN BROCHANTITE, EMPIRE MINE, ALDER CREEK DISTRICT, IDAHO.

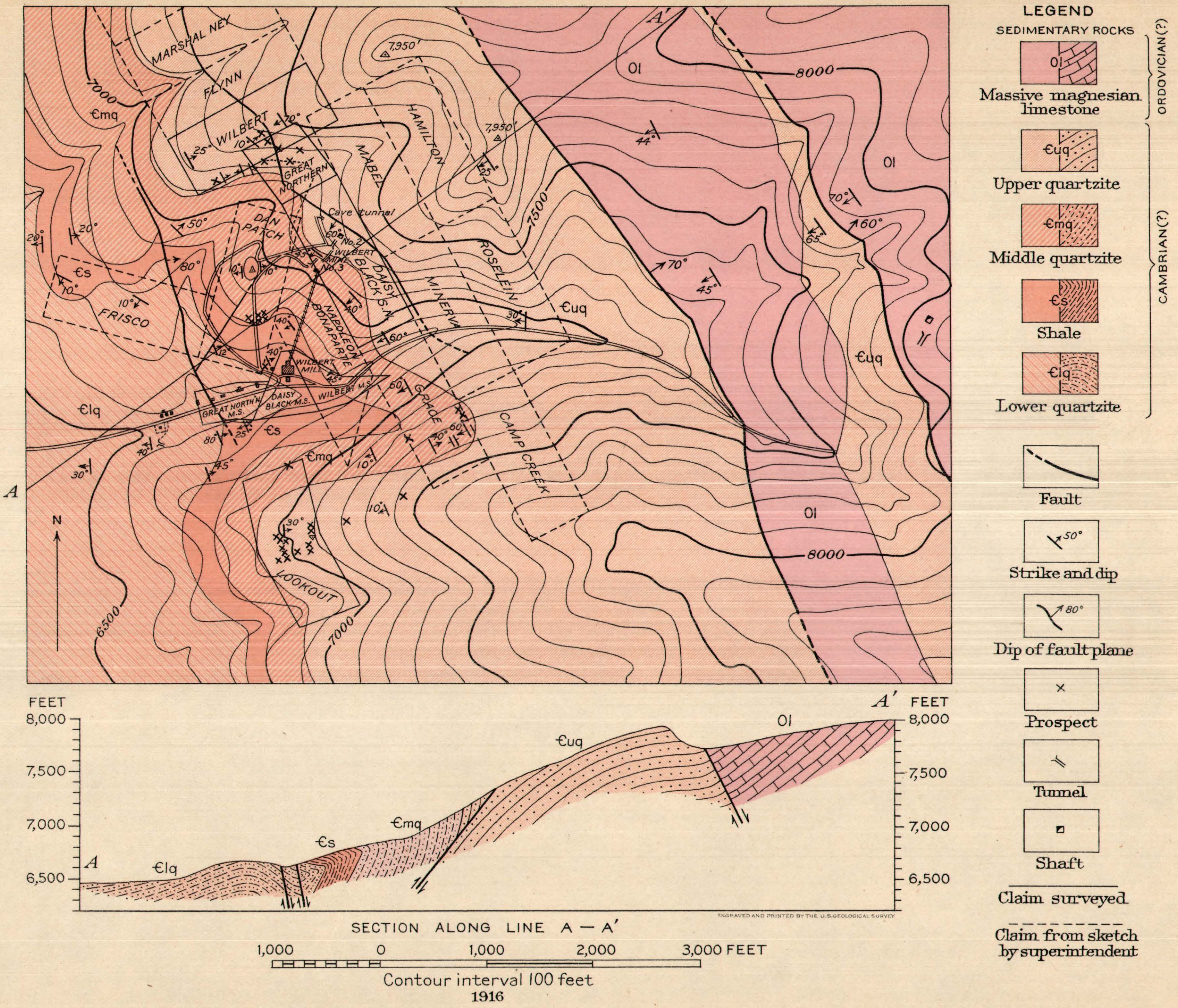
Parallel light. × 50.

C. PARTLY OXIDIZED LEAD ORE, WEIMER MINE, SKULL CANYON DISTRICT, IDAHO.

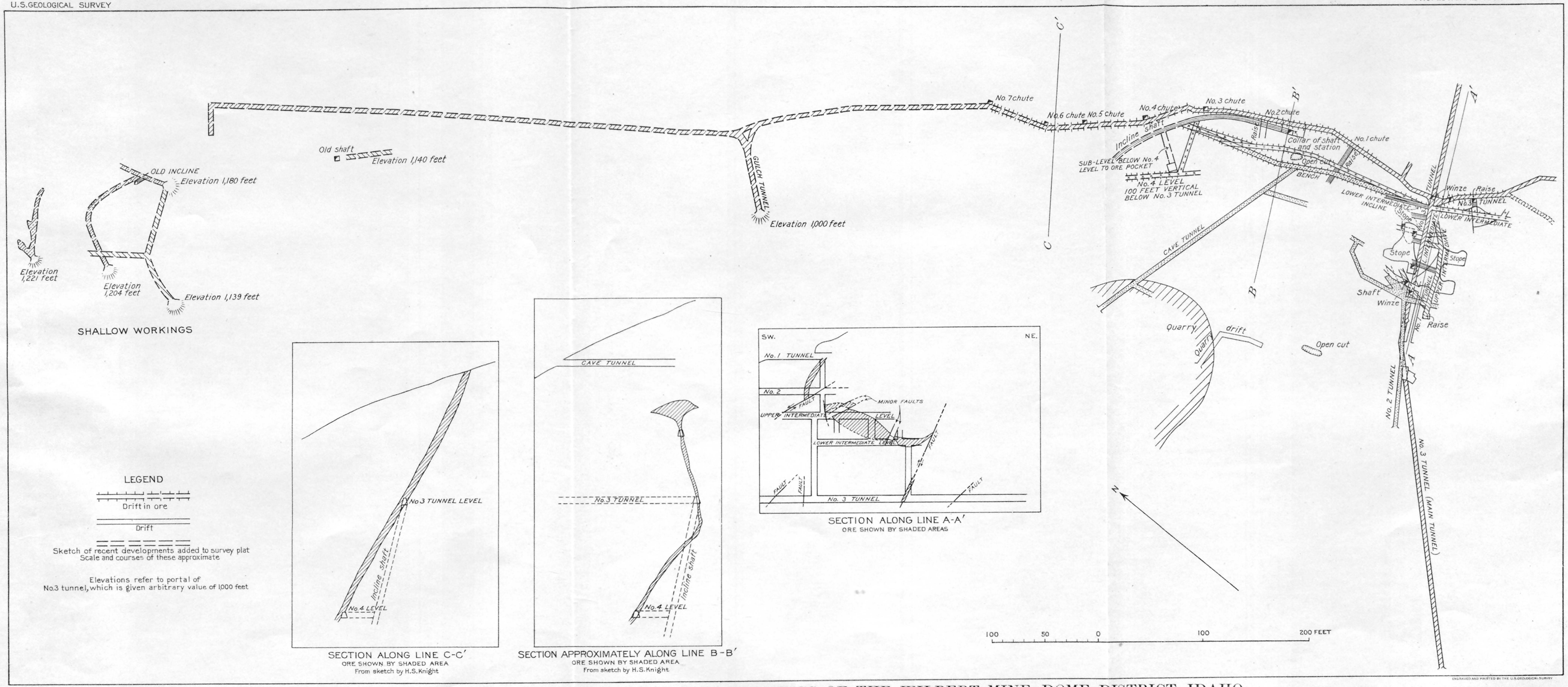
Galena, *g;* barite, *b;* anglesite, *a;* and wulfenite, *w.* Natural size.

D. GALENA (DARK) CEMENTING QUARTZITE BRECCIA, WILBERT MINE, DOME DISTRICT, IDAHO.

Natural size.



GEOLOGIC MAP AND SECTION OF A PORTION OF THE DOME MINING DISTRICT, IDAHO



PLAN AND SECTIONS OF A PORTION OF THE WORKINGS OF THE WILBERT MINE, DOME DISTRICT, IDAHO

INDEX.

60679°—17——9