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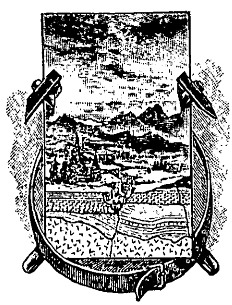
SOME ORE DEPOSITS IN MAINE

AND

THE MILAN MINE, NEW HAMPSHIRE

BY

WILLIAM H. EMMONS



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SOME ORE DEPOSITS IN MAINE AND THE MILAN MINE, NEW HAMPSHIRE.

By WILLIAM H. EMMONS.

INTRODUCTION.

GENERAL STATEMENT.

Metal mining does not rank as an important industry in Maine, for, aside from iron ore, the deposits of which were once worked with some vigor, the metallic production of the State has been small. It contains, however, deposits of nearly all the commoner metals and,

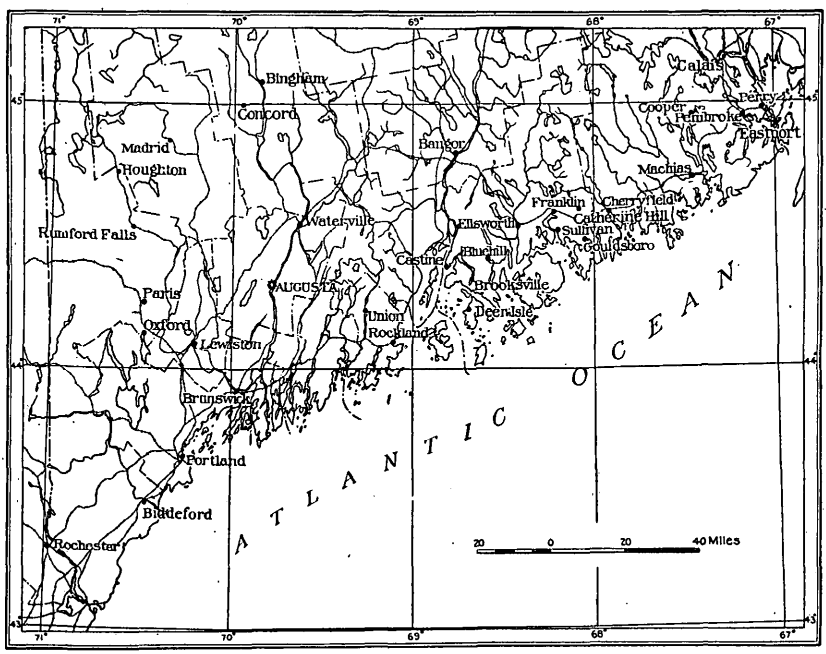


FIGURE 1.—Outline map of southern Maine.

owing to the complex relations of the rocks and the eventful geologic history of the region, the number of types is not surpassed in many areas of equal size in regions of greater mineralization and larger ore deposits.

The economic reconnaissance described in the present paper was made during six weeks of the summer of 1909, in which time all of the most important deposits of the metals other than iron were visited. Figure 1 shows the positions of the towns and of villages near which the mines are located. As many of them are in localities where the areal geology has been worked out in detail and where the structural relations of the rocks are well understood, the history of the ore deposits may be stated with confidence. The conditions for underground work were not good, because nearly all of the mines were closed down and the shafts partly or entirely filled with water, but owing to the slight oxidation of the surface, the relations of the deposits and the character of the ores could be studied in many open cuts and at the higher levels above ground water.

In connection with this work the Milan mine, in Coos County, N. H., was visited. The deposit which is now successfully worked at this mine is only a few miles west of the Maine boundary and closely resembles some of the deposits in Maine. Its description is included in this report for the purpose of comparison.

ACKNOWLEDGMENTS.

The writer gratefully acknowledges his indebtedness to George Otis Smith and E. S. Bastin, whose published papers have supplied most of the geologic data for this report and who have given the writer unpublished notes on some of the mines; to Waldemar Lindgren, of the United States Geological Survey, for direction and criticism; to F. C. Robinson, state geologist of Maine; to Messrs. J. B. Carper and J. B. Morris, of Portland, for many courtesies; and to the owners of the mines and prospects, for the free access granted to their properties.

BIBLIOGRAPHY.

The following list is intended to include the most important publications on the ore deposits of Maine and their associated rock formations:

Bartlett, F. L., Mines of Maine, Portland, 1879.

A discussion of the ores, with numerous assays and notes on the organization and capitalization of various mining companies operating in Maine.

Bastin, Edson S. A pyrrhotitic peridotite from Knox County, Me.—a sulphide ore of igneous origin: Jour. Geology, vol. 16, 1908, p. 124.

Describes a peridotite in which olivine and cupriferous pyrrhotite are intimately intergrown in such a manner as to show contemporaneous age.

——— Eastport folio, Geol. Atlas U. S. (In preparation.)

Numerous geologic data soon to be published in this folio have been freely contributed by Mr. Bastin and are incorporated in the present report.

Carper, J. B. The Milan mine, New Hampshire. Eng. and Min. Jour., vol. 87, 1909, p. 318.

A brief note giving metal contents of ore shipments from the Milan mine.

HESS, FRANK L. Some molybdenite deposits of Maine, Utah, and California: Bull. U. S. Geol. Survey No. 340, 1908, p. 231.

Describes the molybdenite deposits of Cooper, Catherine Hill, and Paris, Me., and concludes that the molybdenite is of pegmatitic origin.

HOLMES, EZEKIEL, and HITCHCOCK, C. H. Preliminary report upon the natural history and geology of the State of Maine, 1861.

This report includes many valuable geological data, with notes on the occurrence of bog iron ores and magnetic iron ores at various places. Several occurrences of lead and zinc and other metals are mentioned, and extracts from a report by N. S. Manross on the Lubec lead mine are incorporated.

HITCHCOCK, C. H. Geology of Maine: Second Ann. Rept. Natural History and Geology of Maine, Geology, 1862, pp. 223–430.

The report includes detailed descriptions of rock formations and cross sections showing the geologic structure at many places along the Maine coast, and gives some running notes on the geology of the northern portions of the State. A list of mineral occurrences and a catalogue with brief descriptive notes on Mount Mica minerals is included. Incorporated in the volume is a report by G. L. Goodale on various occurrences of ore minerals and on the economic possibilities of the iron ores.

JACKSON, CHARLES T. First report on the geology of the State of Maine, 1837.

Some interesting notes of a geologic reconnaissance, with descriptions of building stones and various mineral occurrences.

——— Second report on the geology of the State of Maine, 1838.

Gives some cross sections in the region of Blue Hill, with descriptive notes on the rocks involved. Describes granite, limestone, and shale quarries and the deposits of serpentine on Deer Isle. Includes notes on the technology of iron and of copperas manufacture on Jewel Island, Casco Bay.

——— Third annual report of the geology of the State of Maine, 1838.

Includes notes of geologic reconnaissance, with a list of rocks, ores, and minerals from various localities.

KEMPTON, C. W. Sketch of the new mining district at Sullivan, Me.: Trans. Am. Inst. Min. Eng., vol. 7, 1878, p. 349.

An account of the geology and ore deposits at Sullivan, with several geologic cross sections of that region. A paper of historical value, describing deposits which have not been worked for many years.

MCCASKEY, H. D. Mineral resources of the United States for 1908, pt. 1, Metallic products, U. S. Geol. Survey, 1909, pp. 142, 146, 247, 658.

Notes on various metalliferous deposits of Maine.

SMITH, GEORGE OTIS. Quartz veins in Maine and Vermont: Bull. U. S. Geol. Survey No. 225, 1904, p. 81.

Describes quartz veins at Mount Glines, Oxford County, and a pegmatite near Pittston, Kennebec County, which has been erroneously regarded as a gold ore.

——— A molybdenite deposit of eastern Maine: Bull. U. S. Geol. Survey No. 260, 1905, p. 197.

——— Graphite in Maine: Bull. U. S. Geol. Survey No. 285, 1906, p. 480.

Describes occurrences of graphite near Madrid, Franklin County, and near Yarmouth, Cumberland County.

SMITH, GEORGE OTIS, BASTIN, EDSON S., and BROWN, CHARLES W. Penobscot Bay folio (No. 149), Geol. Atlas U. S., U. S. Geol. Survey, 1907.

This folio furnishes the most comprehensive geologic data for Maine now available, and a considerable portion of the geologic descriptions of the present report are taken from it.

SMITH, GEORGE OTIS, and DAVID WHITE. The geology of the Perry Basin: Prof. Paper U. S. Geol. Survey No. 35, 1905.

This paper is the result of an investigation of the rocks of the Perry Basin to ascertain whether there is a probability of finding coal there. The rocks of this basin are fossiliferous and are interbedded with the lavas, and their study has resulted in disclosing important relationships. The spherulitic rhyolites, which are devitrified and somewhat deformed by metamorphism, are interbedded with fossiliferous Silurian strata and are believed to be the effusive equivalent of the same magma which, solidifying at greater depth, formed the great granite intrusive that extends from Robbinston northward to the vicinity of Calais. The Perry formation, which rests above the Silurian and is less deformed, is made up of conglomerate and sandstone and includes beds of basaltic lavas. Since the Perry carries Devonian fossils the basic lavas are known to be of that age. Pebbles of granite are found in the conglomerate but not in the underlying Silurian rocks.

SMOCK, JOHN C. Mineral resources U. S. for 1882, p. 687.

A list of "Ores, minerals, and mineral substances of industrial importance" which are mined in Maine.

STONE, GEORGE H. The glacial gravels of Maine and their associated deposits: Mon. U. S. Geol. Survey, vol. 34, 1899.

A comprehensive report on the glacial deposits of Maine. A discussion of glacial processes and a comparison of the continental glacier with those of the Rocky Mountains.

GEOGRAPHY.

The State of Maine is for the most part a low plateau, the higher portions of which are deeply trenched by rivers and creeks. Many hills and low mountains rise above this plateau, and it is thickly dotted by lakes and ponds. The coast line is very irregular. Long, narrow bays with deep water channels extend far inland and since these are navigable for small ocean craft transportation facilities are good and freight rates low.

MINING DEVELOPMENT.

Granite and limestone are quarried in large quantities and have a wide market. The metalliferous deposits, although they have not been abandoned, are not now being exploited. Mining was done in a small way in the early part of the nineteenth century. In the second report by Charles T. Jackson on the geology of the State, published in 1838, mention is made of a pyrite mine on Jewel Island, Casco Bay, where copperas and alum were manufactured. Later the iron ores of Mount Katahdin were developed; and for a long term of years, ending about 1890, these deposits produced from 2,000 to 15,000 tons of iron a year. The Lubec lead mines, which were discovered in the late thirties, were worked with some vigor in the early sixties.

The principal period of development was from 1878 to 1882, during which time the districts along the coast were having a mining boom that in all essentials resembled those periods of excitement notable in the history of many western camps. Mining companies with ample capitalization were organized to exploit the deposits of Blue Hill, Sullivan, and near-by districts. Substantial mine buildings were erected; expensive machinery was installed; and in some instances mills, concentrators, or smelters were built. At the Douglas mine, in Blue Hill, large sums were spent on smelters and roasting and leaching plants and several hundred tons of copper was recovered. In 1883 the price of copper dropped considerably and the Douglas and other mines of Blue Hill were closed. The silver mines at Sullivan were closed soon afterward and have since been idle. The mines at Lubec and the Robinson mine, at Concord, have been worked in recent years, and between 1900 and 1907 prospecting was done at several places, but no large operations have been carried on since the eighties.

PRODUCTION OF METALS.

The quantity of metals produced in Maine can not be given accurately. The total value of all metals other than iron is conservatively estimated at $400,000, the larger part of which is copper from the Blue Hill mines. The silver mines at Sullivan and at Byard Point probably yielded at least 5,000 ounces. A number of mines have yielded relatively small quantities of lead and zinc.

GEOLOGY.

The following discussion of the general geology of Maine is taken almost entirely from published papers of G. O. Smith and E. S. Bastin (see pp. 8–9), and from verbal statements made by them, and is intended to include only such data as have a direct bearing on the genesis and history of the ore bodies.

SEDIMENTARY ROCKS.

Ellsworth schist (*pre-Cambrian?*).—The Ellsworth schist is the oldest rock outcropping in the areas of mineralization, and is the country rock for many of the ore deposits. Large areas occur in Hancock County near Blue Hill (see Pl. II), and it extends eastward to Sullivan and beyond. It is composed of highly schistose metamorphic rocks which presumably are the changed equivalents of siliceous shales and argillaceous sandstones. The rock is purple to greenish gray in color and is finely foliated. At most places metamorphism has obliterated all traces of bedding, but on the east shore of Skilleys River in the Mount Desert quadrangle massive quartzite beds alternate with the more argillaceous layers. Under the microscope the chief constituent minerals are seen to be quartz and chlorite. The chlorite occurs in thin parallel plates and gives the rock its schistosity. The quartz fragments have been rotated during the process of metamorphism so that the longer axes lie parallel to the chlorite leaves. Some biotite, muscovite, epidote, and magnetite are present in varying quantities. The schist is intruded by the Castine volcanic rock, by granite, and by diorite and is clearly older than all of these. Since formations known to be later than the Ellsworth are very probably Cambrian, the Ellsworth is presumably very early Cambrian or pre-Cambrian.

Islesboro formation (Cambrian?).—The Islesboro formation, which occupies a large part of Islesboro, is a series of metamorphosed slates and limestones at least 300 feet thick. It is everywhere strongly folded and at many places shows a well-developed slaty cleavage which intersects the bedding planes at high angles. On Seven Hundred Acre Island the slaty members contain intensely crumpled quartz veins. The Coombs limestone member forms the top of the formation and is overlain by the Battie quartzite. In the southern part of Job Island the limestone is interbedded with dark-green layers which seem to be volcanic tuffs or muds of the North Haven greenstone. The slate member likewise contains volcanic material of the same age and origin. In the metamorphism which has affected the formation the limestone has completely recrystallized and the shaly beds have at most places become schists. No fossils have been found in the formation, but on stratigraphic grounds it is thought to be of Cambrian age.

Battie quartzite (Cambrian?).—The Battie quartzite, which consists of massive buff quartzite and quartzite conglomerate several hundred feet thick, rests directly upon the Coombs limestone member of the Islesboro formation without any apparent unconformity. It is well exposed at Mount Battie, a small mountain near Camden. It is not highly crumpled, as is the slate phase of the Islesboro, because it was less yielding. It is believed to be of Cambrian age.

Penobscot formation (Cambrian?).—The Penobscot formation, typically developed along the west shore of Penobscot Bay, is composed of metamorphosed shaly sediments which overlie the Battie quartzite. A distinct and perfect schistosity is commonly present, and the formation is at places intensely folded into isoclinals. At Ducktrap Harbor the slates are intruded by granite, and garnet, andalusite, and other minerals have formed by contact metamorphic processes. The Penobscot formation is believed to be of Cambrian age.

Ames Knob formation (Silurian).—The Ames Knob formation, which is made up of limestones, red shales, and conglomerate, contains Niagara fossils. It has been gently tilted in places, but the compressed folds and minor crumplings characteristic of the Penobscot, Islesboro, Castine, and North Haven formations are entirely absent. Clearly it has been deposited since the time of the regional metamorphism of the country. The basal member is a conglomerate, which includes rounded fragments of North Haven greenstone and of green slate, quartzite, and vein quartz. The upper portion of the formation contains volcanic material, and in the Penobscot Bay quadrangle it grades into the Thorofare andesite. In the Perry Basin fossiliferous Silurian strata are interbedded with rhyolites.

Perry formation (Devonian).—The Perry formation,[a] which in the Perry Basin overlies the Silurian rocks, consists of a lower conglomerate member, above which are beds of basaltic lava and breccia. Above the latter is coarse red and brown sandstone with included conglomerate and lava layers. Above this still is a green amygdaloid and sandstone. The plant remains show the formation to be of Devonian age. Except for certain glacial deposits formed in comparatively recent times by the ice sheet which covered the entire State, no sedimentary beds younger than the Perry are known to occur in the areas of mineralization.

IGNEOUS ROCKS.

Castine formation (Cambrian?).—The Castine formation, which is typically developed on the Castine Peninsula, is made up of light-colored lavas and pyroclastic rocks including rhyolite, dacite, and andesite. These rocks occur as flow breccias, conglomerates, tuffs, intrusive sheets, and dikes. The great bulk of them are metamorphosed dynamically, and some, which were presumably volcanic muds, are highly schistose. Some of the tuffs seem to have been rich in lime carbonate. Chlorite, sericite, biotite, and cordierite have in places been developed in the Castine by secondary processes. Tremolite, biotite, and other minerals have developed by contact metamorphism. A similar association of minerals with sulphides and abundant garnet is found at the Deer Isle mine. (See p. 37.) The Castine formation is in a general way contemporaneous with the Islesboro formation and is believed to be of Cambrian age.

North Haven greenstone (Cambrian?).—The North Haven greenstone, which is extensively developed on the island of North Haven and on neighboring smaller islands, is made up of regionally metamorphosed diabase, basic trachyte, and albite-augite syenite, which occur as tuffs, flows, dikes, and sills. The different varieties, which are at many places indistinguishable, are associated in the most intimate and irregular manner and are believed to be contemporaneous. At some places these rocks show highly developed schistosity. Fibrous actinolite, zoisite, calcite, muscovite, biotite, and chloritic

[a] Smith, G. O., and White, David, Prof. Paper U. S. Geol. Survey No. 35, 1905, p. 28.

minerals are developed by regional metamorphism. The North Haven greenstone is older than the Silurian sediments; and since the Islesboro formation contains much fragmental material of common age and origin with the North Haven greenstone, the latter is believed to be contemporaneous with the Islesboro and nearly contemporaneous with the Castine. Both formations are probably Cambrian.

Thorofare andesite (Silurian).—The Thorofare andesite, which is extensively developed along the Fox Island Thorofare, includes massive porphyritic andesite, amygdaloid, tuffs, flow breccias, and conglomerate. These volcanic rocks, which are not regionally metamorphosed, overlie the upper members of the Ames Knob (Silurian) formation and have about the same attitude. The red shales at the top of the Ames Knob contain volcanic dust, which probably represents the earliest Thorofare eruptions.

Vinalhaven rhyolite (Silurian).—The Vinalhaven rhyolite, exposed in the northwestern part of the island of Vinalhaven, is made up of surface flows. Some are glassy and show flow structure; some are taxitic and spherulitic. They overlie the Thorofare andesite, and at some places fragments of the latter are mixed with the rhyolite flows, the rhyolite constituting the matrix. They are in the main younger than the Thorofare, but near the line of contact of the two formations beds of rhyolite alternate with beds of andesite. It seems probable that the two kinds of lavas were erupted from separate neighboring vents, the volcanic activity beginning with the eruption of the andesite and ending with that of the rhyolite. The andesites and rhyolites are of post-Niagara age, probably late Silurian, and older than the granite.

Granite.—Along the Maine coast from Calais to Portland and beyond granite covers large areas. At most places it is gray or pink and medium grained. The common constituents are orthoclase, microcline, albite, biotite, and muscovite. The granite shows no schistosity such as results from regional metamorphism. It cuts the Ellsworth, the Castine, and other pre-Silurian formations and sends off apophyses into them. The intruded rock is frequently recrystallized near the contact, where some andalusite has formed, but no extensive garnet zones are developed. The granite cuts rocks which are known to be younger than the Ames Knob formation, and it is therefore as late as Silurian. In the Perry Basin no granite pebbles are found in the Silurian, but late Devonian conglomerates (Perry) contain abundant rounded fragments of the granite. The coast granites of Maine were therefore intruded in late Silurian or early Devonian time, and it has been suggested[a] that they are about contemporaneous

[a] Smith, G. O., Prof. Paper U. S. Geol. Survey No. 35, 1905, p. 20.

with certain of the Silurian rhyolites. The granite apparently was not rich in metals, although some of the ore deposits appear to be related to it genetically.

Diorite, etc.—Diorite, diabase, and gabbro are associated with the granite and are believed to be somewhat earlier but essentially contemporaneous differentiations from the same magma. They are dark rocks of medium grain and are free from schistosity. At some places diorite and granite may be seen grading one into the other, and dikes of either rock may cut the other. The Gouldsborough lode is a fissure vein in diorite which near by is brecciated and cemented by medium-grained granite.

Basic lava flows.—In the Perry Basin, near Lubec, in Pembroke, and at many other places in Washington County there are great flows of basic lavas, including basalts, diabase, and "trap rock." In the Perry Basin these are interbedded with sandstone and conglomerate carrying late Devonian fossils, showing that at least some of the flows are of late Devonian age.

Basic dikes.—The granite and the older rocks are cut by dikes of diabase, basalt, and analcite basalt. Some of these are doubtless very old, others are believed to be the intrusive equivalents of the lavas included in the Perry formation, while others still are probably Mesozoic (Triassic?). A basaltic dike cuts across the Robinson lode at Concord, Somerset County, and is very clearly later than the ore. The basalt at the intersection is so fresh that even the olivines show very little of the characteristic alteration to serpentine along cracks.

ORE DEPOSITS.

CLASSIFICATION OF DEPOSITS.

The principal ore deposits of Maine, not including the iron ores nor the gem-bearing pegmatites, may be divided into three groups—(1) deposits formed before the end of the last period of great regional metamorphism; (2) deposits associated with the granite intrusions; and (3) deposits associated with eruptions of diabase or trap.

DEPOSITS OLDER THAN REGIONAL METAMORPHISM.

Distribution and character.—The pre-metamorphic deposits are the most important. All the known representatives are in Hancock County, in the hilly country between Penobscot and Blue Hill bays. They include, stated in order of importance, pyritic copper ores, garnetiferous zinc ores, and siliceous zinc-lead-silver ores. All are in the Ellsworth schist and the Castine volcanic rocks—the Twin Lead, Douglas, Blue Hill, Stewart, Mammoth, Owen Copper, Granger, and Weil Freddie being in the Ellsworth, and the Tapley, Deer Isle, Cape Rozier, Emerson, and Hercules in the Castine. In all the mines in which the ore bodies are exposed the sulphides appear disseminated through the rock, as lenses approximately parallel to the schistosity, or as deformed breccia zones.

The copper deposits near Blue Hill and Brooksville are the most important. All of the mines have lain idle for years and their underground workings are inaccessible, but the character of the ore and its relations to the structure are shown in a number of deep open cuts. Except at the Tapley mine, which is in the Castine formation, the Blue Hill and Brooksville deposits are all in the Ellsworth schist. This is a siliceous sedimentary rock which has been metamorphosed at great depths and under pressure. (See p. 11.) The minerals of the ore are quartz, chlorite, muscovite, biotite, pyrite, chalcopyrite, pyrrhotite, magnetite, arsenopyrite, bornite, chalcocite, and a little zinc blende and galena. Near Blue Hill the deposits lie approximately parallel to the schistosity, striking from S. 87° E. to N. 77° E. and dipping from 45° S. to vertical.

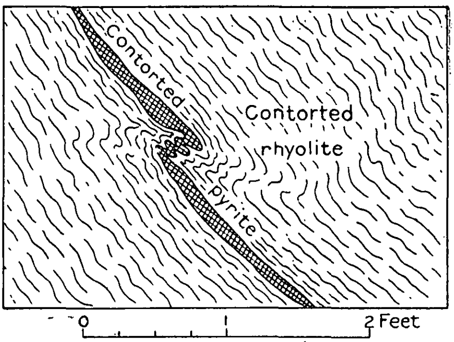


FIGURE 2.—Stringer of contorted pyrite in contorted rhyolite near the Tapley lode.

The lodes are from 5 to 20 feet wide and are said to persist along the strike for several hundred feet. Their central portions are as a rule composed of massive pyrite, with which some chalcopyrite and other sulphides are intergrown. Some quartz is present. Toward the wall thin slabs of schistose quartz and chloritic rock are included in the pyritic ore. These slabs and their constituent minerals lie nearly parallel to the schistosity of the country rock and the trend of the deposit. The walls themselves, which are of the same composition as the slabs, contain stringers of pyrite. Thus there is a gradation from the center of the deposit, which is in the main massive pyrite, to the country rock, which carries only a little pyrite. Comb structure and druses with crustified banding are lacking. At some places, notably in the Twin Lead and Tapley mines, small veins of the sulphides are crumpled parallel to the crumpling of the schist, as illustrated by figures 2 and 3.

In the Milan mine, New Hampshire (see p. 50), deposits of the same general character occur in two overlapping lenses. These two lenses are clearly parts of a single ore body which was torn apart during the process of regional metamorphism. At that time the country rock was deformed by flowage and the pyritic deposit by fracture;

that is, the depth was such that the pressure due to the weight of the overlying rocks exceeded the crushing strength of the quartz-chlorite schist and was inferior to that of the pyrite and quartz. The schistosity of the country rock near by is parallel to the line of separation,

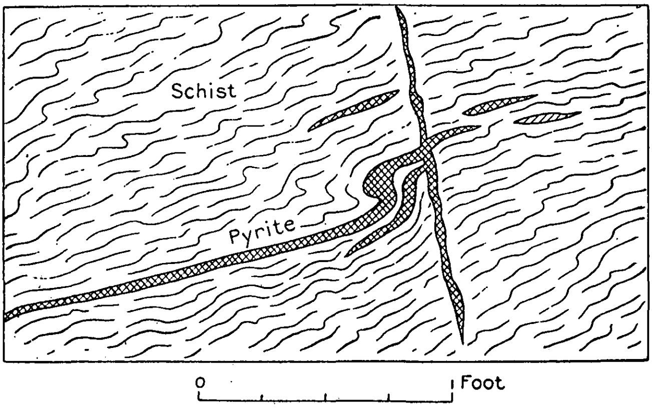


FIGURE 3.—Quartz-pyrite veinlet leading off from Twin Lead lode. The crumpling of the pyrite shows that it is older than the metamorphism of the inclosing Ellsworth schist.

which wraps around the broken ends of the ore body. The fault, if it be so called, is reverse. The place of separation is a highly siliceous portion of the lode and one where the ore is highly crumpled. Perhaps future exploration will show that some of the lodes at Blue Hill which are said to be overlapping in the underground workings

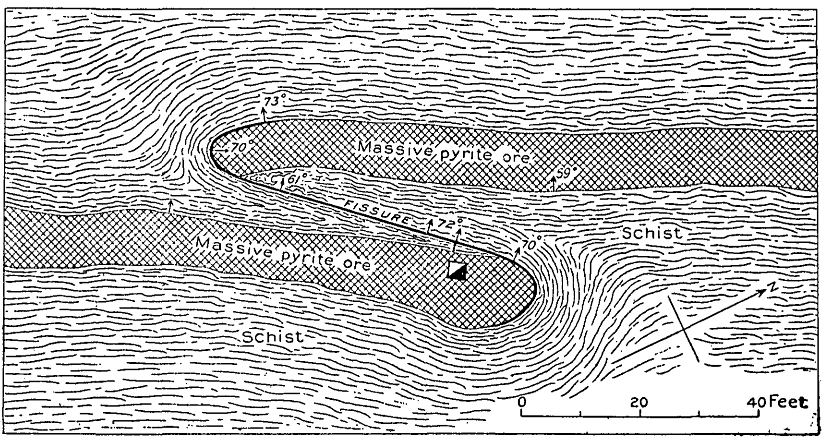


FIGURE 4.—Plan of part of the 115-foot level, Milan mine, New Hampshire.

are joined at their ends by thin fissures and that the schistosity of the country rock along such fissures is parallel to them, as indicated in figure 4.

The wall rock does not show leaching or changes like those commonly resulting from hot-water action of vein-forming solutions, and if ever changed by the processes of hydrothermal metamorphism, the changes have been obscured by later regional metamorphism. The latter process must also have destroyed such features as druses with crustified banding and comb structures, if they were ever present.

Metamorphism.—The behavior of the sulphides during regional metamorphism is noteworthy. Where the ore is nearly pure sulphide, composed of pyrite with some chalcopyrite, it is crushed and recemented by pyrite or by chalcopyrite. It then appears massive and shows little or no schistosity, and one examining the central part of the lode only would not suppose that it had been deformed with the metamorphism of the schists. But near the walls, in the lower-grade ore composed of pyrite, quartz, chlorite, and mica, there is a well-defined schistosity, as shown in figure 5. From microscopic studies it is seen that some of the crushed fragments of pyrite have oriented

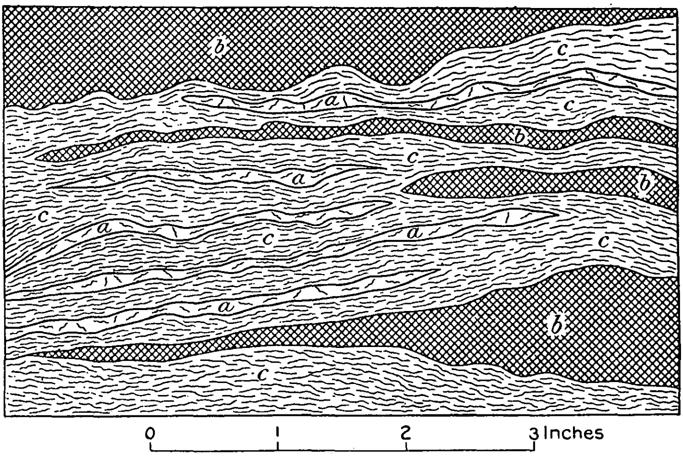


FIGURE 5.—Ore from Twin Lead mine, Blue Hill, Maine. The schistosity was developed after the ore was formed. *a*, Quartz; *b*, pyrite; *c*, chlorite schist. (Compare fig. 8, p. 21.)

themselves parallel to the schistosity between the grains of quartz and chlorite. The crushing is especially well shown where two crystals of pyrite are pressed against each other or against a grain of quartz. If the pyrite crystals are surrounded by chlorite or by mica, they are protected by these yielding minerals, but where two pyrite crystals touch they are shattered and recemented. This feature is illustrated by figure 6, which shows crystals of pyrite that appear in hand specimens to be quite homogeneous. Some perfect crystals of pyrite are formed, however, from iron sulphide dissolved and reprecipitated; such are found mainly in thin crumpled seams where movement has been most intense. Under these conditions cubes and octahedra are developed rather than pyritohedra or pentagonal dodecahedra. The pyrite was deposited in perfect crystals even under the conditions of great pressure and the presence of other minerals. The great crystallizing power of pyrite is well known. It is so great that when pyrite replaces other minerals exactly enough of their substance is dissolved to make a space for the pyrite. As an example may be cited the common case of quartzites in which two or more of the rounded grains of quartz are half dissolved and one perfect pyrite crystal fills completely the space left where the parts of quartz grains were removed.

It is no easy task to determine the character of these deposits before they were metamorphosed, but this may be inferred from their present condition and mineralogical character. The diagnostic value of the minerals is lessened by the fact that nearly all of them may be produced under conditions of regional metamorphism wherever the necessary elements are at hand. Before metamorphism the pyritic copper deposits of Blue Hill and Brooksville were presumably fissure veins of replacement types and disseminated ores along fractured zones. At the zinc mine at Deer Isle (see p. 37) garnet, actinolite, and calcite are abundant and are all microscopically banded parallel to the schistosity of the country rock and to the tablets of massive sulphides. This deposit is believed to be a contact-metamorphic deposit which has been regionally metamorphosed. An alternate hypothesis is that the garnet and tremolite were developed by processes of regional metamorphism when the ore body was subject to the stresses which developed its schistosity. The garnet, however, is not in the perfect crystals which usually form under such conditions, but occurs in crumpled bands, mashed and very highly fractured, alternating with the other minerals. (See fig. 7 and Pl. I, *A*.) Further, garnet and actinolite are rare or absent in the Blue Hill copper deposits, which, with respect to regional metamorphism, have had a similar history. The silver deposits of the Cape Rozier, Hercules, and Emerson mines, which from the character of the ore are believed to belong to this very

FIGURE 6.—Thin section of ore from Milan mine, New Hampshire. The pyrite has been shattered and recemented. *p*, Pyrite; *cp*, chalcopyrite; *c*, chlorite; *q*, quartz.

old group, are not well exposed and their primary origin is not understood.

Origin.—The source of the solutions which deposited the primary ores is not known. The youngest rocks of this area which contain the schistose ores are the greatly metamorphosed Castine intrusives and flows. All of these ores may have been formed during or at the close of the volcanic period of the Castine and North Haven eruptives, and they may have been formed by solutions contributed by intrusive rocks such as the North Haven greenstone and the andesites associated with the Castine formation. The North Haven, which includes diabase, basic trachyte, and albite-augite syenite, occurs at some places as dikes and sills of approximately the same age as the Castine.[a] If the garnetiferous zinc ores of Deer Isle, which seem to have been deposited in calcareous tuffs of the Castine formation, are contact-metamorphic deposits formed near the margin of a North Haven greenstone intrusive, then the thickness of the Castine above the tuffs must have been considerable, for such deposits are not formed at shallow depths.

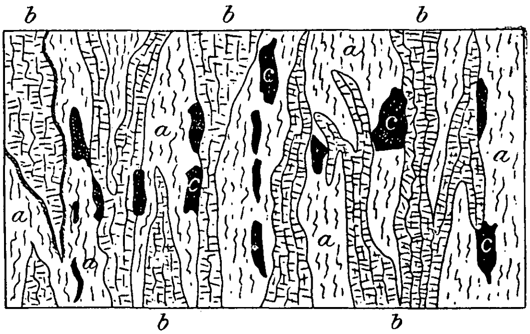


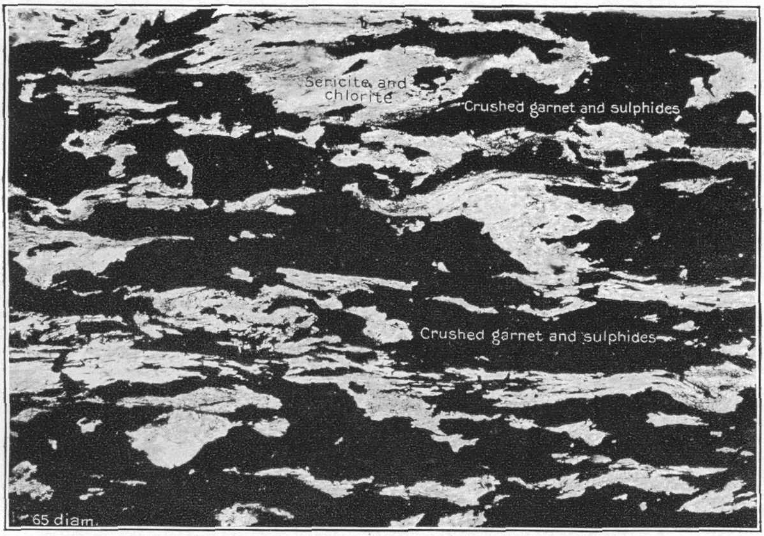
FIGURE 7.—Thin section of schistose ore from Deer Isle mine, showing parallel bands of garnet, sericite, and sulphides. *a*, Chlorite and sericite; *b*, fractured garnet; *c*, pyrite, blende, and galena.

DEPOSITS ASSOCIATED WITH GRANITE INTRUSIONS.

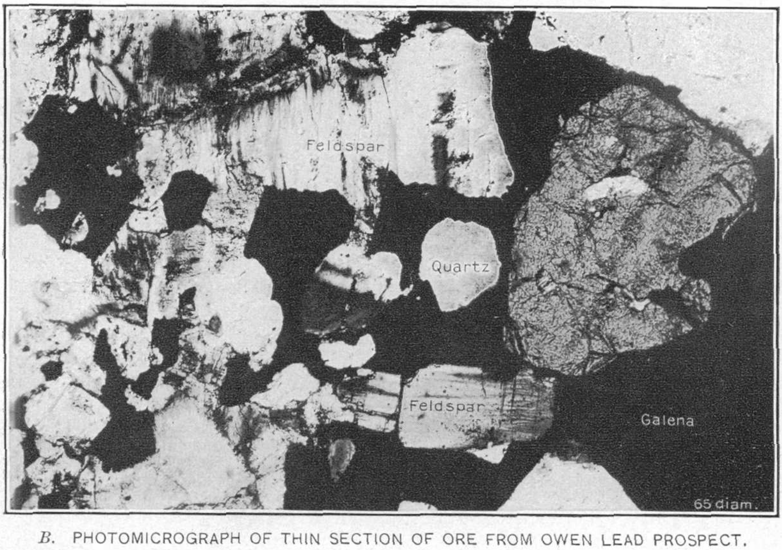
The deposits associated with granite intrusions include the Sullivan, Gouldsborough, and West Franklin mines, the Owen lead deposit at Blue Hill, and the molybdenum mine at Catherine Hill. The deposits are (1) fissure veins in schist and diorite near intrusive granite; (2) molybdenum sulphide ore associated with the pegmatitic phases of the granite magma; and (3) lead sulphide consolidated with the rock-making minerals of the granite.

Fissure veins.—The chief metals of the fissure veins are silver and zinc. The principal minerals are quartz, zinc blende, galena, pyrite, chalcopyrite, and arsenopyrite, but at the Sullivan mines stephanite, argentite, native silver, and tetrahedrite are reported to be present. Pyrrhotite is lacking. In composition and structural features these lodes contrast strongly with the regionally metamorphosed deposits.

[a] Smith, G. O., Bastin, E. S., and Brown, C. W., Penobscot Bay folio (No. 149), Geol. Atlas U. S., U. S. Geol. Survey, 1907, p. 7.



A. PHOTOMICROGRAPH OF SCHISTOSE ORE FROM DEER ISLE MINE.



B. PHOTOMICROGRAPH OF THIN SECTION OF ORE FROM OWEN LEAD PROSPECT.

Although some of them are in the quartz-chlorite (Ellsworth) schist they cut across the schistosity of that rock and include angular fragments of it. These fragments are slightly rounded by the vein-forming solutions and are arranged haphazard with respect to schistosity. Drusy cavities with crustified banding and comb structure are common. These features are illustrated by figure 8, which is a sketch of the ore at Sullivan. Comparison of this ore with the schistose Twin Lead ore illustrated by figure 5 shows many of the points of difference between deposits associated with granite intrusions and those of earlier origin.

The Gouldsborough mine is in quartz diorite, a rock which shows no regional metamorphism and is believed to be an earlier differentiation from the granite magma. Its age relations with the granite are shown near the mine, where broken pieces of the diorite are cemented by granite. The lode is a fissure vein or sheeted zone composed

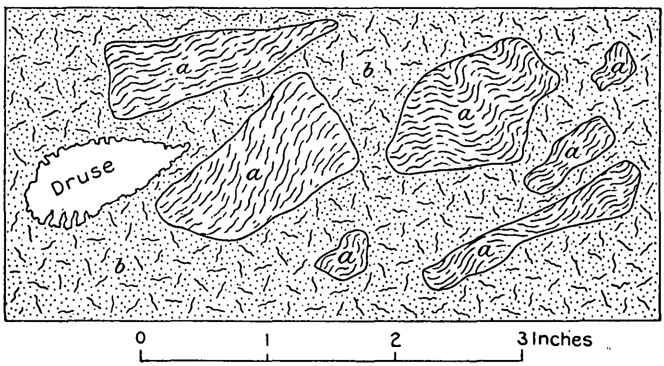


FIGURE 8.—Ore from Sullivan mine The schistosity was developed before the ore was formed. *a*, Fragments of schist; *b*, vein quartz. (Compare fig. 5, p. 18.)

of banded sulphides and quartz. Near the lode the hot solutions have changed the country rock, and much chlorite, some pyrite, epidote, and sericite have replaced the minerals of the quartz diorite.

The zinc mine at Concord, near Bingham, Somerset County, is a siliceous deposit occupying the crest of an anticlinal axis. The ore is not metamorphosed and may belong to the granite period of mineralization, but the deposit is isolated and the geology of the surrounding area has not been studied with sufficient care to justify an attempt to classify it.

Molybdenite and lead deposits.—The Catherine Hill molybdenite deposit (Pl. III, *B*) and the Owen lead deposit (Pl. I, *B*) are magmatic segregations which belong to this period of mineralization. The galena and the molybdenite inclose well-shaped crystals of feldspar rounded on the edges, but clearly idiomorphic, or nearly so. The sulphides solidified at the time the rock was formed. A similar crystallization of pyrrhotite in peridotite from Knox County has been described by E. S. Bastin.[a]

DEPOSITS ASSOCIATED WITH DIABASE AND TRAP.

The deposits associated with the diabase and trap include those of the Lubec lead mine, the Denbow Point mine, and the copper and zinc prospects in Pembroke, all of which are in Washington County and in the Eastport quadrangle. The country rock is at no place greatly metamorphosed by pressure and the ores show no schistosity. The galena-blende ores at Lubec are deposited in thin fissures and in brecciated zones. The ores at Pembroke are deposited in vesicular cavities and in nonpersistent fractures in basic flows, as illustrated by figure 9.

The deposits of this group show drusy cavities and crustified banding. The minerals of the ore are quartz, dolomite, calcite, galena, zinc blende, pyrite, chalcopyrite, bornite, and arsenopyrite. The oxidized ore is composed of quartz, limonite, and a little manganese oxide and copper carbonate. The Lubec ores carry some silver. No pyrrhotite is present in the ores of these deposits and no massive magnetite, although the crushed ore yields a trace of magnetic dust—possibly an oxidation product. As a result of the reactions of the vein-forming solutions with the wall rock much secondary chlorite and calcite were formed but only a little sericite.

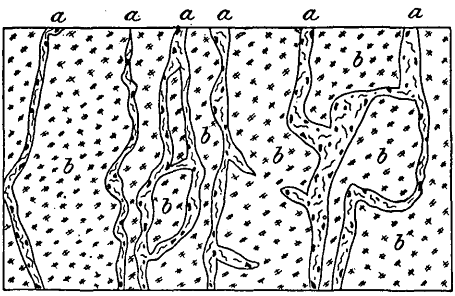


FIGURE 9.—Brecciated diabase cut by quartz and sulphides, Pembroke mine. *a*, Quartz and ore; *b*, diabase.

MINERALOGY.

The following list includes the most important minerals of the deposits, with brief descriptive notes of their occurrence. Only the most important of the rock-making minerals are mentioned and no attempt is made to list the minerals of the pegmatites, except those which are closely related in genesis to some of the ore deposits. The pegmatites of Maine are to be treated in a forthcoming paper by E. S. Bastin.

Actinolite.—Developed by secondary processes in some of the regionally metamorphosed schists and intimately associated with the garnetiferous ores at the Deer Isle mine.

[a] Pyrrhotitic peridotite from Knox County, Maine—a sulphide ore of igneous origin: Jour. Geology, vol. 16, 1908, p. 124.

Albite.—A common constituent of the granite and some other igneous rocks. Appears as idiomorphic crystals surrounded by galena at the Owen lead mine and as crystals surrounded by molybdenite at the Catherine Hill molybdenite mine.

Apatite.—A common accessory constituent of the granite and other igneous rocks. Crystals of apatite are surrounded by galena in the Owen lead prospect.

Argentite.—Reported from the silver mines at Sullivan.

Arsenopyrite.—Present in the copper mines at Blue Hill and in the silver mines at Sullivan, but not abundant at either place.

Augite.—Abundant in the basic igneous rocks, but not noted in connection with any of the ore deposits.

Barite.—Not abundant. A little was noted on the dump at the Deer Isle mine and at the Sullivan mine.

Biotite.—A common constituent of the schist. Is present in the schistose copper ores.

Bornite.—Not abundant in any of the deposits but appears in some of those at Blue Hill, at the Lubec lead mine, and at the prospects in Pembroke.

Calcite.—Rare or absent in the schistose ores at Blue Hill but present in the Deer Isle zinc ore, in the Lubec lead ores, and in the wall rock near the lodes along some of the fissure veins.

Cerargyrite.—Reported from the silver mines at Sullivan.

Chalcocite.—Not abundant in any of the deposits. Sparingly present as dark films on chalcopyrite at the copper mines near Blue Hill.

Chalcopyrite.—Present in nearly all of the deposits. An important ore mineral in the schistose copper ores of Blue Hill.

Chlorite.—Abundantly developed in the schist and intimately associated with the schistose ores; also the most abundant mineral formed by metasomatic processes along the fissure veins in igneous rocks.

Copper, native.—An oxidation product of the copper-bearing sulphides. Reported from the Douglas mine and the Owen mine at Blue Hill.

Cuprite.—Sparingly present in the zone of oxidation of the copper deposits.

Epidote.—Appears with quartz in some small veinlets in Pembroke. Developed with chlorite and sericite in the quartz diorite wall rock of the Gouldsborough lode.

Galena.—Sparingly present in nearly all of the deposits. More abundant at the Lubec and the Bingham mines. Intergrown with feldspar at the Owen lead prospect.

Garnet.—Abundantly present in the schistose ores of the Deer Isle mine, where it has been regionally metamorphosed. Sparingly developed in intruded rocks near intruding granite and pegmatite.

Gold.—Sparingly present in the Blue Hill mines and reported in small quantities from most of the other mines visited. Occurs sparingly in some river gravels. Not an abundant ore mineral in Maine.

Graphite.—Occurs in pegmatite and in metamorphosed schists at several localities.

Gypsum.—Present in ore of Sullivan mine.

Hematite.—Either hematite or the hydrated oxide turgite is usually present in the oxidized ore of all groups.

Kaolin.—Formed from feldspar and other minerals in the igneous rocks by reactions with surface waters.

Limonite.—The most abundant mineral in the oxidized ore. Appears near the surface of nearly all the deposits.

Magnetite.—Occurs in noticeable quantity in the Blue Hill copper ores and in the Deer Isle zinc ore. Minute specks are present in the ore of some of the later silver lodes but only as the merest traces.

Malachite.—Rare in the copper deposits of Blue Hill. Forms on the old slag dumps, but was not noted in the ore. A little is present in the copper prospects at Pembroke.

Manganese oxide.—Present in the oxidized ore at Blue Hill and occurs in the Lubec lead ore.

Microcline.—See Orthoclase.

Molybdenite.—Present in granite and in pegmatite at Catherine Hill.

Muscovite.—Occurs in the quartz-biotite schist and is associated with the ores of that rock. Forms as sericite along the silver lodes by metasomatic replacement, but not abundantly.

Olivine.—Fresh olivine is abundant in the later trap rocks and decomposed olivine in the greenstones.

Orthoclase.—Orthoclase and microcline are prominent minerals of the granite and associated pegmatites.

Pyrite.—The most abundant and a ubiquitous mineral of the ores.

Pyroxene.—Present in the more basic igneous rocks.

Pyrrhotite.—Present in all of the copper ores at Blue Hill and in some of the lead and zinc ores near by, and sparingly present in the Bingham zinc ore. Not present in the silver lodes associated with the granite.

Quartz.—Present in most of the igneous rocks, in all of the sedimentary rocks, and in the ore of all groups of deposits. The pegmatitic quartz contains fluid inclusions.

Rhodochrosite.—Absent in most deposits; a little noted at the Deer Isle zinc mine.

Sericite.—See Muscovite.

Siderite.—Gangue mineral at the Pembroke copper prospects.

Silver, native.—Reported from the Eggemoggin and Sullivan mines.

Specularite.—Nowhere abundant. Some was noted at the Stewart copper mine and on the Hercules dump.

Stephanite.—Reported from the Sullivan mine.

Stibnite.—Reported from the Sullivan mine and from the copper deposits near Blue Hill.

Talc.—Present in ore of Sullivan mine.

Tetrahedrite.—Reported from the Sullivan mine.

Tourmaline.—Present in the pegmatite at Mount Mica and at Crocker Hill.

Tremolite.—Developed in the wall rock at the Tapley mine.

Wolframite.—Dr. Charles T. Jackson[a] found wolframite (iron-manganese tungstate) and molybdenite in granite near Blue Hill Falls.

Zinc blende.—Present in deposits of all groups, but sparingly so in the Blue Hill copper deposits.

DISTRIBUTION OF OUTCROPS.

In relatively late geologic times the entire State of Maine was covered with an immense glacier or ice sheet which had slowly invaded it from the northwest. Much of the territory now under the sea was doubtless overlain by this ice sheet, for it is known to have extended to far outlying islands. As the climate grew warmer the ice gradually receded northwestward, but upon the country it had

[a] First report on the geology of the State of Maine, vol. 1, p. 103.

covered it left drift of various types which concealed many outcrops of rocks and their contained ore deposits. After the ice had gone the land slowly rose to higher levels above the sea. At some places sea-worn pebbles are found as much as 225 feet above the present coast.[a] The emergence of the land was very slow, however, and at times it remained stationary long enough for imperfect bars, spits, and similar coast features to be formed.[b]

In some places in the region of Penobscot Bay, when the land was about 20 or 25 feet below its present position,[c] there was a noteworthy halt in the process of elevation, and during this period terraces were built by the sea and cliffs were cut in exposed places. Doubtless the glacial drift was washed away at many places, laying bare the rocks and ore deposits. Subsequently the land rose 20 or 25 feet. Thus along the ragged seacoast about 25 feet above the present shore line was exposed a belt which had at favorable places been lately washed by the waves. Along this belt the rocks are well exposed, and in it many of the ore deposits have been discovered. The Deer Isle, Eggemoggin, Hercules, Emerson, Cape Rozier, Sullivan, Denbow Point, Lubec, and other deposits are near the water's edge, not more than a few feet above sea level, and some of them doubtless owe their exposed condition to the washing of the waves in this zone of delayed emergence. Some of the deposits named were discovered below high tide and worked by means of cofferdams, but most of them were found some 10 to 20 feet above high tide.

In many regions creeks and brooks which cut through the overlying mantle of soil furnish good exposures of the rocks, and the banks along such streams are favorable positions to search for outcrops of ore deposits. In Maine, however, these smaller streams have been engaged in removing the glacial material left at the comparatively late recession of the ice sheet and have not had sufficient time to do much cutting in the solid rock; consequently, their banks do not furnish the customary quota of outcrops. At some places, where the glacial ice with its included stones planed off the country rock, the latter has not yet disintegrated into soil and still remains bare; in such places a few deposits have been discovered, among which are the Tapley mine, in Brooksville, and some of the copper prospects in Pembroke.

OXIDATION AND SECONDARY ENRICHMENT.

When sulphide ores remain for a long time near the surface of the earth the oxygenated surface waters react on their minerals. Oxides, carbonates, and other compounds are formed, and the quartz

[a] Stone, G. H., Mon. U. S. Geol. Survey, vol. 34, 1899, p. 48.
[b] Willis, Bailey, Bull. Geol. Soc. America, vol. 14, 1903, p. 205.
[c] Smith, George Otis, Bastin, E. S., and Brown, C. W., Penobscot Bay folio (No. 149), Geol. Atlas U. S., U. S. Geol. Survey, 1907, p. 13.

and other difficultly soluble minerals are usually disintegrated. As a result of these processes the outcrop of a sulphide ore body appears in general as a mass of iron oxide or of quartz stained with iron oxide and other oxygen compounds. In cupriferous deposits carbonates commonly appear at the outcrop, but such are rare in the oxidized copper ores in Maine.

The depth to which the oxides extend is variable and depends largely on the shattering or fracturing of the sulphide deposits, which makes them more pervious to water, and on the length of time they have been exposed to surface waters. In Maine the deposits are not greatly fractured, and since glaciation is of relatively recent date they have not been long exposed to highly oxygenated surface waters. At many places the sulphides appear at the very surface, and mixed oxides and sulphides are very common in the outcrops. At the Douglas mine, in the open pit just west of the main shaft, the oxidized ore ends abruptly along a fracture which cuts the lode 5 or 10 feet below the outcrop. In the Milan mine (New Hampshire) the depth of oxidation is greater and the lode is partly oxidized to 40 feet below the apex, while oxidation along watercourses extends 100 feet below the surface. Compared with that of deposits in unglaciated regions oxidation in northern New England is slight.

Where the upper portion of a lode is in the zone of oxygenated waters, some of the minerals pass into solution. Pyrite and chalcopyrite on oxidation yield sulphuric acid and iron and copper sulphates. If it happens that a lode is highly shattered below the zone of oxidation these sulphates are carried downward in solution, and when they reach a zone in which there is relatively little oxygen they react with pyrite and chalcopyrite and deposit chalcocite. This process is commonly termed secondary enrichment, for it changes the lower-grade sulphides to richer copper ores. In the Milan mine the process has operated to some extent to enrich shallow chalcopyrite and cupriferous pyrite; and masses of these minerals where fractured are commonly coated with a film of black chalcocite. Similar ore was observed on the dumps of the Douglas mine, near Blue Hill, and at other mines near by, but there is no evidence that this process was carried far. The tight condition of the deposits and the brief period of exposure to oxygenated waters are unfavorable to much sulphide enrichment or to extensive oxidation, and if the deposits extend downward to great depths the copper content will not be much lower than it is near the surface.

FUTURE OF THE MINES.

Lead, zinc, and silver.—It does not appear likely that any of the lead, zinc, and silver deposits which have been examined will become important sources of these metals. Possibly some of them could be worked in a small way by hand sorting and by the more simple methods of mechanical concentration, but the ore is in the main of low grade. It is nowhere greatly oxidized and could easily be concentrated mechanically, but no ore body yet developed is of sufficient size to warrant the erection of a plant large enough to work with real economy. A presumption against the existence of rich deposits associated with granite is afforded by the chloritic alterations of the walls along the veins—alterations supposedly due to the ore-depositing solutions given off by the granite as it solidified. Chlorite is formed extensively by regional dynamometamorphic processes, to some extent in contact metamorphism, and as a secondary mineral by hydrothermal metamorphism of the wall rocks along certain productive lodes in diabase and other basic rocks. Where associated with fissure veins in acidic rocks, it has generally been formed by the weaker ore-bearing solutions; and in regions of large and rich deposits it is found some distance away from the veins, in places where apparently the solutions had already spent too much of their power to change the country rock greatly and to deposit ore. Again, near the great vein deposits the wall rock has commonly undergone strong sericitization, pyritization, silicification, and other processes; and these were relatively inactive when the lead, zinc, and silver veins associated with the intruding granite were formed and were not strongly active when the ores associated with the trap rocks were deposited.

Copper.—The pyritiferous deposits near Blue Hill are not at present sufficiently exposed to warrant an estimate of their value, but a deposit which is in many respects similar is now successfully worked at Milan, N. H. (See p. 50.) To judge from the mineral composition at that place, it would seem that somewhat similar methods could be applied to the Blue Hill ores. These ores or concentrates from them would be rich in sulphur and could without doubt be sold advantageously to acid works. If the paper mills of New England should ever adopt the practice followed at some European plants, they could make their sulphur dioxide at a lower cost for the raw material from pyrite than from native sulphur, a large tonnage of which is now utilized in paper manufacture. The schistose garnetiferous sulphide ore at Deer Isle has proved refractory to metallurgical treatment, but possibly one of the newer methods of oil flotation could be successfully employed to separate the garnet from the sulphides if the amount of ore exposed is sufficient to warrant an installation.

SUMMARY OF GEOLOGIC EVENTS AS RELATED TO ORE DEPOSITS.

From studies of the geology of the Penobscot Bay quadrangle,[a] the Perry Basin,[b] and other areas, and from the observed relations of the ore deposits, the geologic events related below are deduced.

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[a] Smith, G. O., Bastin, E. S., and Brown, C. W., Penobscot Bay folio (No. 149), Geol. Atlas U. S., U. S. Geol. Survey, 1907.

[b] Smith, G. O., and White, David, Prof. Paper U. S. Geol. Survey No. 35, 1905.

Pre-Cambrian and Cambrian time.—In pre-Cambrian or possibly in early Cambrian time a series of siliceous shales and impure sandstones were laid down in extensive beds and were subjected to regional metamorphism. Later, probably in Cambrian time, the impure sand which now forms the slates of the Islesboro formation was deposited. During the deposition of this formation great volcanic activity prevailed; the acidic Castine rocks, which included both flows and dikes and some calcareous water-laid tuffs, were formed. These were followed very closely or perhaps in part were accompanied by the North Haven eruptives. These North Haven diabases, basic trachytes, and albite-augite syenites included both effusive and intrusive bodies. The garnetiferous zinc ores at the Deer Isle mine, which are in a calcareous phase of the Castine near the contact of the North Haven greenstone, were probably formed by processes of contact metamorphism during North Haven time, and part or all of the Blue Hill and Brooksville pyritiferous copper ores are believed to have been formed at the same period or in connection with the Castine eruptions. Near the close of the period regarded as Cambrian and following closely the igneous activity, the Coombs limestone, a member of the Islesboro formation, the Battie quartzite, and the slates of the Penobscot formation were successively laid down.

After the eruptions, after the copper and the zinc ores were deposited, and after the Penobscot beds, which later became slates, were laid down, the region was subjected to profound dynamic metamorphism. A schistose structure was developed in all of the rocks, but is most marked in those containing the most clay. The ore bodies also took on a schistose structure. As a result of this, in the Deer Isle zinc deposit garnet, amphibole, quartz, sulphides, and magnetite were compressed into thin crumpled parallel bands. The copper deposits also were greatly affected, but since these were simpler in mineral composition the resulting deposits were different. At the center of the deposits the large and relatively pure masses of pyrite were broken and recemented with pyrite and chalcopyrite. Where there was a higher percentage of quartz with the pyrite the two minerals were broken into unequidimensional fragments and these oriented themselves in lines parallel with the schistosity. Where considerable clayey material was present chlorite and the micas formed in great abundance and oriented themselves with their long directions nearly parallel with the schistosity and parallel to the long dimensions of quartz and pyrite fragments. Where a pyrite crystal was protected by a cover of clayey material it did not break, but the micaceous minerals formed inclosing spheres around it and bent to accommodate themselves to it; but where such a pyrite crystal was pushed through the chlorite against another crystal of pyrite, both were shattered. There was much recrystallization and some pyrite was redeposited as perfect crystals. Quartz seems also to have been dissolved and reprecipitated to some extent, but not in crystal form. During metamorphism some of the ore bodies were probably separated by a peculiar kind of faulting, which must have taken place at a depth that was in the zone of flow for the wall rock and the zone of fracture for the ore. Such a fault, as illustrated by the Milan mine (see p. 50), is strikingly sigmoidal and laps around both of the ends of the broken ore body, the schistosity following its complexly curving plane, as shown by figure 4. The overlapping lenses which are said to constitute some of the Blue Hill deposits probably resulted from similar movements. Just when these events happened is not known, but they were before the beginning of the deposition of the Ames Knob formation, which lies unconformably above the metamorphosed series. The Ames Knob is of Silurian age (Niagaran) and is not metamorphosed, its lowest member being a basal conglomerate which contains well-rounded pebbles of black and green slates, quartzites, and vein quartz.[a] The metamorphosed rocks and ore deposits are therefore older than the Silurian, but how much older is not known.

Silurian time.—While the Silurian rocks were being deposited volcanic forces again became active. The Thorofare andesite was erupted and was followed by the Vinalhaven rhyolite. At about this time gentle folding and some faulting took place, accompanied or followed by the great intrusions of granite and diorite. The intruded rocks were metamorphosed to some extent, though not profoundly, by the gases and solutions given off. The granite intrusions all along the coast were probably formed at about the same time, and if so they are of post-Niagaran or early Devonian age, for pebbles of the granite are found in the late Devonian (Perry formation). It seems that the granites were in the main poor in metals, but some of their pegmatitic phases carried a little molybdenum sulphide, which was deposited when the pegmatites solidified. Quartz veins were deposited also by solutions which originated in the granite. Some of these veins were barren, but some carried ores of silver, zinc, and lead. The Sullivan silver veins, which are in the Ellsworth schist, were deposited at this time, and the Gouldsborough zinc-silver lode in diorite is presumably of the same age. The mineralizing solutions altered the wall rock to chlorite, epidote, and sericite, but this action was not intense. The galena-feldspar ore in a prospect on the Owen farm at Blue Hill appears to have consolidated directly from the granite.

Devonian time.—After the granite had solidified it was eroded; and above it the lower conglomerate member of the Perry formation was laid down in late Devonian time. Subsequently basic lavas were

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[a] Smith, Bastin, and Brown, folio 149, 1907, p. 4.

extravasated upon these, and upon the lavas Denovian sandstones were deposited, which were in turn overflowed by vesicular basic lavas. In connection with the same general period of basic eruptives, and probably in late Devonian time, the Lubec, Denbow Point, and Pembroke lead and zinc deposits are believed to have been formed. Still later—probably in Mesozoic time—basaltic dikes cut the various formations; at Concord, in Somerset County, an ore deposit which in general character most closely resembles those associated with the granular intrusives is cut by such a dike.

Quaternary time.—Other events that affected the ore deposits in Mesozoic or in Tertiary time are not known. If the deposits exposed to weathering were deeply oxidized during those periods then the oxidized portions were planed off by the great ice sheet which covered the country in Pleistocene time. In Recent time, however, since the retreat of the ice, the sea has cut cliffs in which many of the deposits are exposed, and as a result the seashore has become a favorable place for outcrops. The copper lodes, where fractured, have been to a very trivial extent leached by descending surface waters, which have deposited chalcocite films on the older sulphides, but these lodes were presumably so completely recemented during the period of regional metamorphism and have been disturbed so little since that time that they have not been greatly affected by the processes of chalcocitization. Some oxidation has taken place, but as a rule it has extended to only slight depths—generally to not more than a few feet below the outcrop.

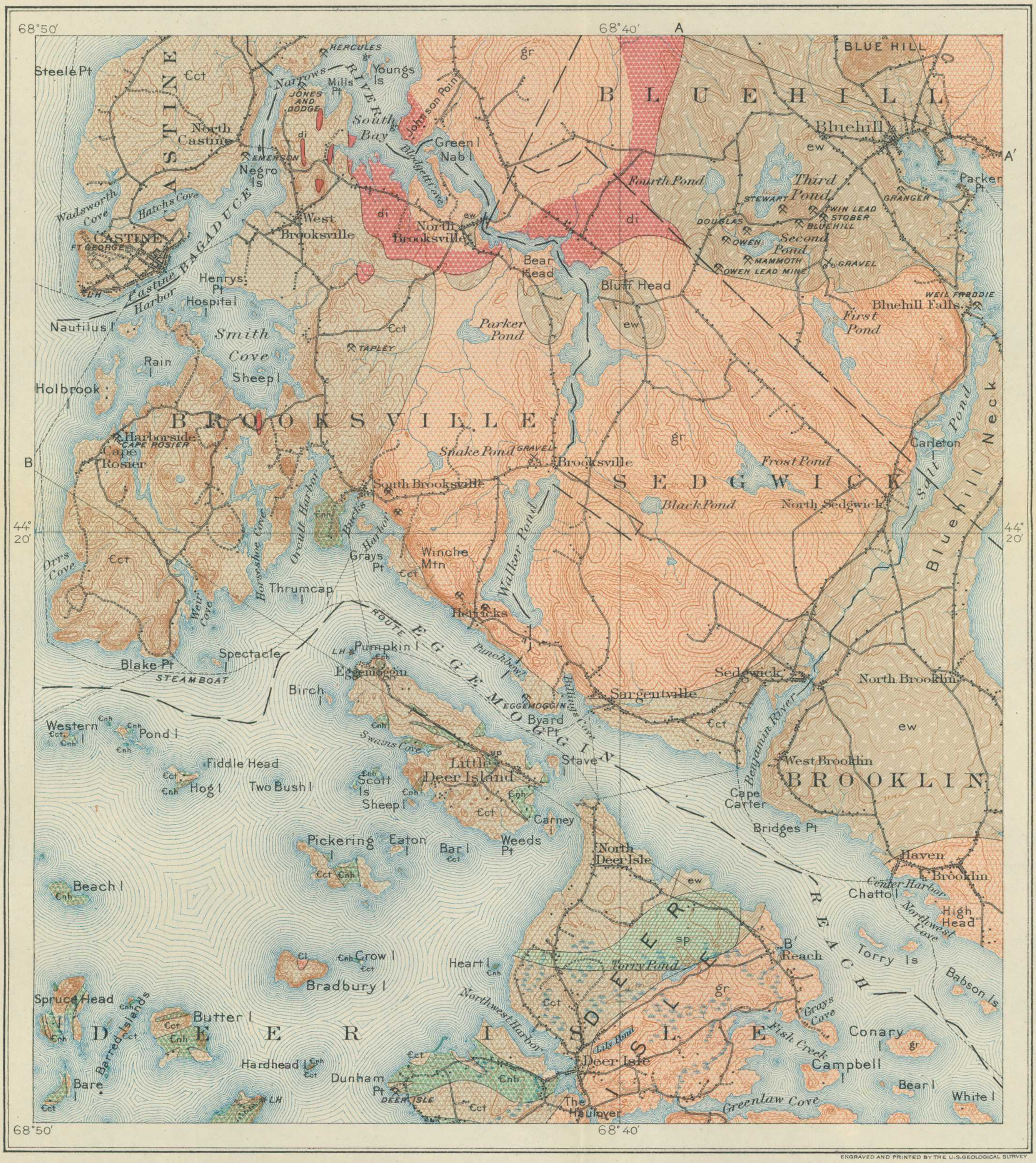
DESCRIPTIONS OF MINES.

HANCOCK COUNTY.

GENERAL STATEMENT.

The southwestern part of Hancock County has been geologically mapped in detail by George Otis Smith, E. S. Bastin, and C. W. Brown in the Penobscot Bay folio (No. 149) of the Geologic Atlas of the United States, published by the United States Geological Survey. Plate II of the present paper is a reproduction of a part of the geologic map of this folio, with the addition of symbols indicating the positions of the mines in the district. Figure 10 is a section showing the relations of the rocks along the line A–A′ in the plate, but extending beyond it, and figure 11 is a section along the line B–B′.

The principal rocks with which the ores are associated are the Ellsworth schist, the schistose volcanic rocks, and the granite and closely related diorite. The relatively small area of Ellsworth schist at Blue Hill includes nearly all of the schistose deposits of pyritic copper ores. A large area of quartzose schist extends northwestward



GEOLOGIC MAP OF THE MINERALIZED AREA OF BLUEHILL, BROOKSVILLE, DEER ISLE, AND CASTINE, MAINE

H. M. Wilson, Geographer in charge.
Topography by U.S. Coast and Geodetic Survey, W. H. Lovell, and Hersey Munroe.
Triangulation by U.S. Coast and Geodetic Survey.
Surveyed in 1900-1903.
SURVEYED IN COOPERATION WITH THE STATE OF MAINE.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.
1909

Geology by George Otis Smith, E. S. Bastin, and C. W. Brown.
Surveyed in 1902-1904.
SURVEYED IN COOPERATION WITH THE STATE OF MAINE.

LEGEND

SEDIMENTARY ROCKS

CAMBRIAN ?

€i — **Islesboro formation** *(slates and schists locally quartzitic with shaly quartzose, and occasionally pure limestones)*

CAMBRIAN OR PRE-CAMBRIAN

Metamorphic

ew — **Ellsworth schist** *(crumpled green and gray schists)*

IGNEOUS ROCKS

DEVONIAN ?

gr — **Biotite granite** *(fine, medium, and coarse grained granite)*

di — **Diorite, diabase, and gabbro** *(earlier differentiation from the granite magma)*

SILURIAN ?

sp — **Serpentine**

CAMBRIAN ?

Contemporaneous with upper part of Islesboro formation

€nh — **North Haven greenstone** *(diabase, basic trachyte, and albite-augite syenite, occurring as flows, dikes, sills, and pyroclastic rocks)*

€ct — **Castine formation** *(rhyolite, andesite, and some dacite, occurring as flows, dikes, and pyroclastic rocks)*

⚒ Mine ⚒ Quarry ⚒ Gravel pit

from Frenchman Bay along Union River far to the north of Ellsworth. This area includes the mines at Sullivan and Franklin.

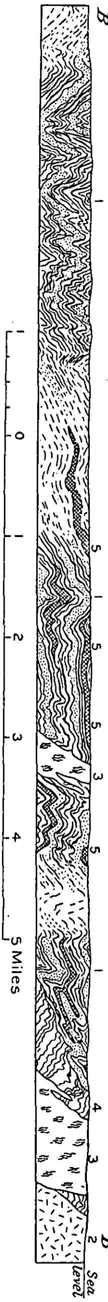


FIGURE 11.—Section along line B–B', Plate II. 1, Castine formation; 2, biotite granite; 3, serpentine; 4, Ellsworth schist; 5, North Haven greenstone.

The schistose igneous rocks which belong to the Castine formation cover extensive areas in the western part of the region represented on Plate II. The Tapley mine, which in many respects resembles the Blue Hill copper deposits, is inclosed in the Castine, and the Deer Isle, Eggemoggin, Cape Rozier, Hercules, Emerson, and other deposits are in the same formation. The granites and associated diorite which are intrusive in the schistose rocks cover a large part of the area represented on Plate II, but in this area the only deposit known which is genetically related to the granular rocks is at the Owen lead prospect.

In the eastern part of the county, at Sullivan and at Franklin, fissure veins of silver ore which cut the schist near granite contacts have been deposited by solutions which are believed to have had their origin in the granite. Still farther east, the Gouldsborough, a lode of argentiferous zinc blende in diorite is supposed to have had a similar genesis, and just east of the Hancock County line at Cherryfield a zinc deposit is inclosed in schist not far from granite to which it may be genetically related. The molybdenite deposits of Catherine Hill are associated with pegmatite veins which cut the granite.

DOUGLAS MINE.

The Douglas mine, located about 2 miles southwest of Blue Hill village, is owned by interests identified with the Pittsburg and Montana Company, of Butte. The mine was opened in 1878 and was worked until 1883 and is said to have produced between two and three

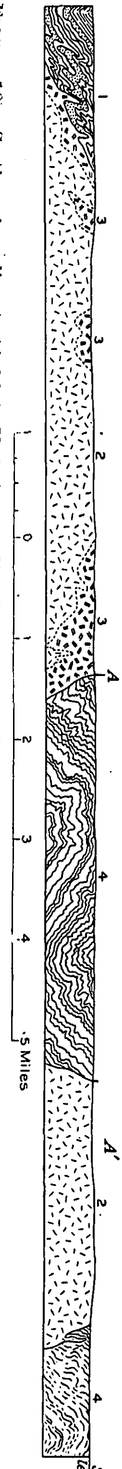


FIGURE 10.—Section along line A–A', Plate II, but extending beyond area shown. 1, Castine formation; 2, biotite granite; 3, diorite, diabase, and gabbro; 4, Ellsworth schist.

million pounds of copper which yielded about $300,000. It was reopened in 1908 and sampled by its present owners. A two-compartment shaft inclined 47° is sunk 245 feet on the incline. A second two-compartment shaft, about 150 feet to the east, is sunk to a depth of 75 feet. Both were under water when the mine was visited. The deep shaft is equipped with steam power and skip. On the surface are numerous heaps of roasted ore and the ruins of a concentrator, blast furnace, precipitation plant, and refining furnace. The deposit is a lode said to be from 12 to 20 feet wide, striking eastward and dipping about 45° S.

An analysis of the better grade of ore made for the company by S. P. Sharples, of Boston, is given below:

Analysis of copper ore from the Douglas mine.

SiO_2	35.8
Fe	25.9
CaO	.13
Mn	.52
Al_2O_3	3.11
S	28
Cu	5.88
	99.34

This ore carries 0.01 ounce gold and 1.17 ounces silver to the ton.

The country rock is a rather siliceous phase of the Ellsworth schist and is composed of quartz, muscovite, and biotite, with pyrite scattered liberally through it. Where exposed in an open cut a few feet west of the main shaft the lode follows the schistosity of the country rock. The ore minerals observed in the pit and on the dump are pyrite, chalcopyrite, pyrrhotite, chalcocite, arsenopyrite, zinc blende, magnetite, and cuprite. Stibnite, tennantite, and tetrahedrite have also been reported.[a] The gangue minerals, which in places are banded with the sulphides, are quartz, sericite, biotite, and chlorite. A little molybdenite is present, with pyrite and muscovite. Thin sheets of native copper are reported to have formed in joint seams of the ore. Oxidation in the open pit is nearly complete to a depth of 5 feet and ends at a prominent joint plane which dips to the south at a very low angle.

TWIN LEAD MINE.

The Twin Lead mine is on the Sargentville road about 1½ miles southwest of Blue Hill. A three-compartment inclined shaft now filled with water is reported to be 200 feet deep. The lode has been

[a] Smock, J. C., Mineral Resources U. S. for 1882, U. S. Geol. Survey, 1883, p. 687. Bartlett, F. L., Mines of Maine, p. 23.

stoped out open cast to a depth of 12 feet for about 70 feet along the strike. The ruins of a smelter and small slag dump show that some ore has been treated. The lode, which is about 10 feet wide, is in the Ellsworth formation and parallels the schistosity, striking N. 77° E. and dipping about 45° S. The ore minerals are pyrite, pyrrhotite, magnetite, chalcopyrite, and a little bornite. The gangue minerals are quartz, sericite, biotite, and chlorite. The sulphides outcrop at the surface and oxidation is inconsiderable. The pyrite is disseminated through the rock and in bands parallel to the schistosity, but lenses of ore, consisting mainly of pyrite, chalcopyrite, and quartz, are found here and there in the lode. A stringer of pyrite, making off from the main lode, is shown in figure 3; its associations show that the quartz and pyrite are older than the metamorphism of the schist, a fact also indicated by the arrangement of the minerals in the lower-grade ore.

BLUE HILL MINE.

The Blue Hill mine is located 1,050 feet west of the Twin Lead mine, on the opposite side of the road. Large dumps of ore and country rock similar to that of the Twin Lead surround the ruins of a shaft, and roasted heaps of ore lie near by. Near the mine are the ruins of a concentrating mill, and below this are the ruins of a smelter and slag dump. The lode is not accessible above or under ground. At the low hill just south of the mine a 75-foot tunnel is driven eastward in pyrite-bearing schist cut by large masses of white quartz. Southwest of this tunnel, on the southwest slope of the hill on which the Blue Hill mine is situated, a deep open cut about 75 feet long and 10 to 15 feet wide is driven S. 85° E. into the hillside. The country rock is quartzite impregnated with pyrite and cut by numerous closely spaced veinlets of pyrite. It carries also some large masses of nearly pure pyrite and some chalcopyrite.

STEWART MINE.

The Stewart mine is southeast of Third Pond, between this and Second Pond and about 100 yards northeast of the Douglas mine. A two-compartment shaft said to be 150 feet deep but now filled with water is sunk southward at an inclination of 57° on an eastward-striking lode. The ore on the dump is similar to that of the Twin Lead but is more siliceous. About 150 feet north of the shaft another lode about 10 feet wide strikes S. 87° E. and dips 70° to 80° S.; it is opened in a long, deep cut exposing a great mass of pyritiferous rock. The country rock, which is the Ellsworth schist, contains considerable biotite, but is more siliceous than at the Blue Hill and Twin Lead. Actinolite, tremolite, biotite, sericite, chlorite, and zircon are microscopically visible. Near the lode the quartzose schist carries considerable pyrite and some chalcopyrite, magnetite, and pyrrhotite. The trend of the deposit agrees with the schistosity of the rock, and as at the Blue Hill and the Twin Lead the pyrite bands are crumpled like the silicates, showing that the ore was deposited before the regional metamorphism of the country.

MAMMOTH MINE.

The Mammoth mine is located on the south shore of Second Pond. one-half mile from the Douglas. A vertical shaft, now full of water, is said to be 100 feet deep. The country rock is Ellsworth schist, here very quartzitic. The gangue is quartz, biotite, muscovite, and actinolite. The ore minerals are pyrite, chalcopyrite, pyrrhotite, and specularite, with a very small amount of zinc blende and galena. On the dump are several hundred tons of highly pyritiferous rock which carries a noticeable amount of the copper sulphides.

OWEN MINE.

The Owen mine is located on the west side of Second Pond, half a mile southwest of the Douglas. The country rock is a siliceous phase of the Ellsworth schist with a schistosity that strikes S. 82° E. and dips 45° S. A pit 25 feet long and 12 feet wide is sunk in sulphide ore and pyritiferous quartzite to a depth of 30 feet. The workings do not show the direction of the lode. The minerals are quartz, biotite, sericite, pyrite, chalcopyrite, pyrrhotite, and magnetite. According to Mr. Arthur Owen thin sheets of native copper have been found in joint planes of the rock. The ore is said to carry more than 3 per cent of copper.

OWEN LEAD PROSPECT.

The Owen lead prospect is one-half mile west of the Mammoth copper mine and north of the granite batholith which cuts siliceous Ellsworth schist near by. In 1909 the small pit 20 feet deep was full of water. The Ellsworth here is composed of quartz, biotite, muscovite, and other minerals and is cut by dikes of granite which make off from the large mass. There is no pronounced contact metamorphism of the schists; no garnet appears to have been formed; actinolite is rather more abundant than elsewhere; magnetite and pyrrhotite are developed but are not more abundant than at other places in the schist a mile or more away from the contact, where they have formed through dynamometamorphism. In one of the small granite dikes there is considerable galena, a little pyrite, and some chalcopyrite, all of the sulphides being intergrown with feldspar, quartz, biotite, and muscovite. Magnetite or pyrrhotite, which are common in the copper ores, are not present in the lead ore.

While the deposit appears to be small, the genesis of the ore is of peculiar interest. The granite near by is medium grained and is composed of quartz, feldspar, biotite, and a little sericite. The feldspars are orthoclase, microcline, and a little albite. The galena-bearing granite is not coarse like most pegmatites but is of medium grain like all the granite near by. It has the same minerals in the same proportion except that albite, a small amount of which is present in the granite, is even less abundant in the ore. The galena, which in some specimens makes up one-fourth or more of the mass, is intergrown with the feldspars and surrounds well-formed idiomorphic feldspar crystals, the sharp corners of which have been rounded off before the galena solidified. A little apatite is also inclosed in galena and some chalcopyrite is intergrown with galena. The structure is the same as in some diabases, where feldspar crystals are surrounded by a matrix of augite, but in the granite here galena takes the place of augite. A photomicrograph of a thin section of this ore is shown in Plate I, *B*. None of the minerals are highly altered, but some chlorite is developed by decomposition of biotite and the feldspar is slightly clouded by decomposition to kaolin. The white mica present is mainly or altogether primary. The ore is clearly the consolidation of a molten magma.

GRANGER MINE.

At the Granger mine, about three-fourths mile south of Blue Hill, a shaft, now inaccessible, is sunk in the Ellsworth schist. In the ore exposed on the dump the gangue minerals are quartz, biotite, chlorite, and sericite. The sulphides noted are pyrite, chalcopyrite, and bornite.

WEIL FREDDIE MINE.

The Weil Freddie mine is a few rods east of the village at Blue Hill Falls, on the north shore of the bay. An inaccessible shaft, reported to be 100 feet deep, is sunk in pyritiferous Ellsworth schist which carries some copper pyrite.

TAPLEY MINE.

The Tapley mine is on the farm of Charles P. Tapley, about 2½ miles southwest of Brooksville. It was opened about thirty years ago and a small amount of ore has been shipped for experimental purposes. The mine changed ownership in 1907 and some development work was then done, but these operations were soon suspended, and in 1909, when the property was visited, the mine was idle and the underground workings full of water. A shaft is sunk on the lode to a depth of 80 feet and according to report some 200 feet of drifts and crosscuts are turned from it. The deposit was exposed at several places in open cuts.

The country rock is the Castine formation, which is here, in the main, a rhyolitic breccia, but which locally includes a dark rock, presumably andesite. Both of these rocks are regionally metamorphosed, with the development of secondary biotite, sericite, and tremolite. Small colorless garnets are developed also in the andesite. Some of the rhyolite contains numerous specks of microscopic magnetite and in hand specimens is as dark as the andesite. The schistosity of this rock, which though not pronounced is well defined, strikes northeastward. The rhyolite is at some places strongly plicated and cut by quartz veinlets which cross its schistosity. Northwest of the lode a dike of basalt only slightly metamorphosed cuts the Castine.

The deposits outcrop on a glaciated surface. For 500 feet along the lode the ground is cleared and open cuts are dug at several places. The lode strikes N. 47° E., parallel to the schistosity, and is a wide zone of shattered and altered rhyolite. The sulphides are pyrite and chalcopyrite, both of which are found at the very surface; films of limonite, hematite, cuprite, and bornite appear in small amount in the cracks of the ore, which is not highly shattered. The ore includes fragments of the country rock which are slightly silicified, but the lumps of pyrite ore on the dump contain but little quartz. These fragments contain much more sericite and chlorite than the country rock a few feet from the vein. Some of the ore in the open pits is rhyolite which contains secondary tremolite, sericite, biotite, and chlorite, with flakes and specks of pyrite, the latter constituting perhaps 10 per cent of the mass. A little magnetite and pyrrhotite is present. Some of the ore impregnated with pyrite shows laminated sericite and quartz, and some of the chalcopyrite is feebly laminated parallel to the micaceous sheen which shows when the ore is held in suitable position, suggesting that the sulphides were formed before the regional metamorphosing processes had ceased operation. This relationship is indicated also by the crumpled stringers of pyrite which are found near the lode. One of these is shown in figure 2.

EGGEMOGGIN MINE.

The Eggemoggin mine is at tide water on Byard Point, about a mile west of Sargentville. Two shafts, now inaccessible, are sunk in devitrified rhyolite breccia of the Castine formation. The lode is not exposed, but the dump showed altered rhyolite impregnated with sulphide and galena. Some of it is strongly sheeted and cut by parallel stringers of white quartz, which also carries sulphides. The principal minerals are quartz, sericite, pyrite, arsenopyrite, chalcopyrite, galena, and zinc blende. The ore is reported to carry good values in silver. Native silver is said to have been present. According to report, shipments of ore were made in the late eighties, but the mine has not been worked for many years. The ruins of an old metallurgical plant stand near by.

DEER ISLE MINE.

The Deer Isle mine is located at tide water on Dunham Point, about 3 miles west of Deer Isle village. This mine was first worked in the seventies and was reopened in 1907, since when it has produced about 900 tons of ore. A shaft is sunk on the lode at an inclination of 45° to a depth of 260 feet, and on the 200-foot level drifts about 100 feet long are turned in either direction. Near the shaft stopes are carried up within a few feet of the surface. When the mine was visited stopes below the 100-foot level were inaccessible.

The mine is in the Castine formation, presumably an altered porphyritic rock with phases which were probably calcareous water-laid tuff. The North Haven greenstone outcrops near by and is regarded as of approximately the same age as the Castine formation.[a]

The lode follows the schistosity of the country rock, striking from N. 22° E. to N. 70° E., and dips from 45° to 65° N. The schist is heavily impregnated with sulphides for a width of 1 to 8 feet. Sheets of pure sulphide an inch or two wide persist for several feet along the dip and strike and are overlapped by similar sheets. The rock between these is composed of innumerable paper-thin sheets of alternating sulphide and garnet.

The sulphides are steel-colored zinc blende, pyrite, galena, and chalcopyrite. Intergrown intimately with them is a considerable amount of magnetite. The gangue minerals are garnet, actinolite, sericite, calcite, chlorite, quartz, and rhodochrosite; a little barite was noted on the dump. Figure 7 is a sketch of a thin section of the ore, showing parallel bands of garnet, sericite, and sulphide. Without doubt the deposit has been regionally metamorphosed since it was formed, and the highly schistose structure of the lode, which parallels that of the country rock, has resulted from the same dynamic forces that developed the schistosity in the country rock. According to George H. Holden the high-grade ore carries zinc 30 per cent, lead 16 per cent, silica 12 per cent, copper $2\frac{1}{2}$ per cent, and gold $2.50 a ton. The minerals with the exception of barite and rhodochrosite are those commonly found in contact-metamorphic deposits, but they have been crushed or redeposited by regional metamorphism.

The sulphides have been crushed, recemented, and in part recrystallized. The chlorite and mica seem to have been completely

[a] Smith, Bastin, and Brown, folio 149, Geol. Atlas U. S., p. 5.

dissolved and recrystallized with longer axes parallel to the schistosity and to the orientation of the lode. The garnet is so highly fractured that in places it is almost opaque in thin section when the nicols are not crossed. None of the garnet shows the crystal form. Garnet, as is well known, is formed in igneous rocks, in contact-metamorphic deposits in some deep veins, and by regional metamorphism. In igneous rocks it is nearly always idiomorphic. In contact-metamorphic deposits it is either massive or idiomorphic and very often shows such optical anomalies as double refracting rings. It may have schistose structure when it replaces schists, but it is not highly fractured like the Deer Isle garnets, and some crystals usually have the crystal outline or else show the double refracting rings. In the veins of the deep zone it is usually idiomorphic. The garnet of the Deer Isle mine is not idiomorphic, is greatly crushed, and does not show double refracting rings. Under the microscope it has the color and general appearance of andradite and without much doubt is contact-metamorphic garnet which has been regionally metamorphosed by pressure. (See fig. 7 and Pl. I, *A*.)

CAPE ROZIER MINE.

The Cape Rozier mine is at Harborside, across the harbor from Castine. The country rock is schistose pyroclastic tuff of the Castine formation. This is cut by diorite, which shows no schistosity. On the dump are fragments of the Castine formation cut by thin sheets of pyrite and chalcopyrite and stained with green copper carbonate. The two shafts are inaccessible. Some ore on the dump of upper shaft is composed of calcite, zinc blende, pyrite, and chalcopyrite. The ore observed shows no schistosity.

HERCULES MINE.

The Hercules mine is between Penobscot and Castine, just above the Bagaduce Narrows. A shaft sunk at tide water is now submerged. The country rock is the Castine formation, which, near the ore body, is highly silicified and somewhat sericitized. Some ore on the dump shows quartz, sericite, zinc blende, galena, chalcopyrite, pyrite, pyrrhotite, and specularite.

JONES & DODGE MINE.

The Jones & Dodge mine is one-half mile southwest of the Hercules, on the south shore of the Bagaduce Narrows. The country rock is the pyroclastic phase of the Castine formation, which at the mine shows a schistosity striking northward. In the dark biotitic portion of the country rock certain bands carry small amounts of pyrite, chalcopyrite, galena, and zinc blende.

EMERSON MINE.

The Emerson mine is near the Castine ferry on the west shore of Bagaduce River. A two-compartment shaft, sunk near the shore, is under water. The country rock shown on the dump is devitrified rhyolite. Some of this is brecciated and has sulphide ore deposited between its fragments. The amount of ore on the dump is very small. The minerals noted are galena, zinc blende, pyrite, magnetite, and pyrrhotite.

SULLIVAN, WAUKEAG, AND PINE TREE MINES.

At West Sullivan, east of Frenchman Bay, several mines are located along tide water. These include the Sullivan, Waukeag, and Pine Tree

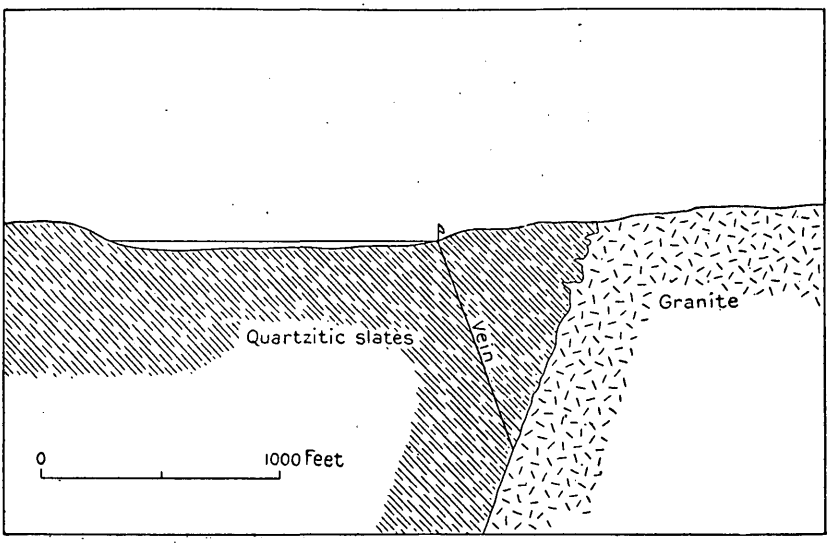


FIGURE 12.—Cross section of the Sullivan mine. (After Kempton.)

mines, all of which, according to report, are on the same lode. The Sullivan lode, which was discovered in 1877, outcrops below high tide. A cofferdam was built and this and the Waukeag mines were worked from 1878 to 1884. The Waukeag, which operated a 14-stamp mill and smelting furnace, is reported to have produced 25 tons of silver-lead bullion. All the mines were inaccessible in 1909.

The country rock is dark-gray micaceous schist, probably the Ellsworth. Near the mines the schistosity strikes S. 75° E. and is practically vertical. At places it is cut by a dark rock, presumably a diorite. A few rods west of the Waukeag shaft are large outcrops of medium-grained granite, composed of quartz, feldspar, biotite, and muscovite. The Waukeag shaft, which is vertical, is reported to be 410 feet deep. A second shaft near by on the same property is 60 feet deep. On the Sullivan, about 180 feet southeast of the Waukeag, a shaft is driven 290 feet on a steep incline to the northeast. A cross section of the vein, after C. W. Kempton, is shown in figure 12. The

Milton shaft, about one-fourth mile down the bay and along the strike of the lode, is sunk to a depth reported to be 260 feet. According to report the lode was not encountered in a 400-foot crosscut to the southwest.

To judge from the ore on the dump the deposit is a clean-cut vein filling a fissure in the schist and is not regionally metamorphosed. The gangue is quartz, barite, talc, and gypsum; the sulphides, which are not abundant in the gangue, include zinc blende, galena, pyrite, chalcopyrite, arsenopyrite, and a gray sulphide which is probably brittle silver. Threads of native silver are said to have been found 10 feet below the surface. Magnetite, specularite, and pyrrhotite are absent. The quartz is usually massive, but is also found as acicular crystals pointing to the center of a druse. Brecciated fragments of the schistose country rock are included in the ore and the rounded edges of these show that they were partly dissolved by the ore-depositing solutions. These relations are shown in figure 8. The schist is not strongly leached near the lode, but chlorite and sericite have developed through metasomatic processes.

The banded ore is not schistose like the pyritic copper ores in the Ellsworth schist and is clearly of later age; it was probably formed at the time of the intrusion of the granite.

C. W. Kempton,[a] who was engaged as a mining engineer at Sullivan in 1877, gives the following information relating to the Sullivan mine:

Proceeding with the shaft, at about 30 feet depth, the vein, composed of quartz, with more or less slate highly impregnated with sulphides, was found to be 4 feet wide. * * * The ore is essentially silver, sulphides and native, in quartz and slaty gangues, with slight amounts of iron, zinc, etc., as sulphides, and also galena. Of the silver minerals, stromeyerite is most plentiful, stephanite next, argentite (silver glance), common, native silver in flakes very plenty, threads frequent, lumps occasional.

Ruby silver is exceedingly rare; antimonial silver has been found. The occasional yellow copper sulphide met with has a peculiar luster and runs very rich in silver.

As stated above, the course of the vein is from northwest to southeast, with the strike of the slate running parallel to the line of contact of the granite. The vein is in the slate, dipping at an angle of 70° from the horizon, northeasterly, toward the granite, which it probably reaches in less than a thousand feet. The slate also dips toward the granite at this place about 37° from horizontal, although at some other places not more than 12°.

At the contact of the slate and granite the latter often penetrates the bedding of the slate, in known instances nearly 200 feet. The granite is much cut up by dikes of black trap, which also runs into the slate, faulting the vein in several places.

GOULDSBOROUGH MINE.

The Gouldsborough mine is in the town of Gouldsborough, about 9 miles southeast of West Sullivan. A shaft 150 feet deep is sunk on

[a] Trans. Am. Inst. Min. Eng., vol. 7. 1878, p. 349.

the lode and a drift is driven northwestward 75 feet from the 100-foot level. The mine is now under water. On the surface the vein is stoped, underhand, in an open cut 150 feet long, which reaches a maximum depth of about 50 feet. In the early eighties some ore was shipped. The country rock is dark quartz diorite, which shows no sign of contortion or regional metamorphism. One mile to the south there are large areas of granite and near the mine the brecciated diorite is cut by granite veinlets. Near the lode the diorite is somewhat decomposed and locally it is brecciated and cemented by rhodochrosite.

The lode is a fissure vein which strikes N. 63° E. and is approximately vertical. It varies in width from 6 inches to 2 feet and is composed of banded quartz and sulphides, with angular slabs of country rock. The metalliferous minerals are galena, chalcopyrite, pyrite, zinc blende, and a very small amount of magnetite. The proportion of sulphide to quartz is high and the ore is said to carry considerable silver. The hydrothermal metamorphism of the wall rock is clearly shown. The quartz diorite is a medium-grained rock, is very fresh, and is composed of oligoclase, andesine, hornblende, biotite, quartz, orthoclase, and pyrite. Within a few feet of the lode this is altered to a rock composed of chlorite, sericite, epidote, quartz, and pyrite. The chloritization does not extend far from the lode. A rod or two away a brecciated quartz diorite is, as already stated, cemented by coarse granite. The quartz diorite is certainly older than the granite, and the granite is probably the source of the ores.

The outcrop is partly oxidized, but sulphides appear within a few feet of the surface. The banding of the ore, the open druses parallel to bands, the brecciation of diorite and its inclosure in ore, the absence of crenulation and foliation in the vein, and the characteristic hydrothermal metamorphism of the wall rock show that the deposit belongs to the class which postdates regional metamorphism.

FRANKLIN EXTENSION MINE.

The Franklin Extension mine is 2 miles west of Franklin station and one-eighth mile west of West Franklin. The lode is a narrow fissure vein in contorted schist, presumably the Ellsworth. It strikes N. 18° E. and is approximately vertical. Two shafts, said to be on the same lode, are sunk about 300 feet apart. The ore is composed of quartz, arsenopyrite, galena, and pyrite. Granite, cutting the Ellsworth schist, is exposed within a few feet of the lode. The deposit, which is said to carry silver, is banded and shows comb structure. It is clearly of later age than the metamorphism of the schist.

COPPEROPOLIS MINE.

The Copperopolis mine is near Egypt, 4 miles west of Franklin station. Two hundred yards west of the mine house three pits are sunk in the contorted Ellsworth schist, which carries seams of quartz and pyrite with stains of copper carbonate. The Harvey Elliott prospect is about 300 yards east of the mine house. The shaft was under water when visited, but to judge from the dump the country rock is the Ellsworth schist intruded by a dark igneous rock which is slightly schistose. The ore consists of thin sheets of quartz, calcite, rhodochrosite, pyrite, and chalcopyrite.

CATHERINE HILL MOLYBDENUM MINE.

The Catherine Hill molybdenum mine is at the north end of Tunk Pond, near the summit of Catherine Hill. The deposit was described by F. L. Hess[a] in 1908.

The country rock is a medium-grained granite composed of pink and white feldspar (orthoclase and albite), quartz, biotite, and muscovite. The granite is cut by aplite dikes from one-half inch to 4 inches wide, some of which dip about 15° N. It is cut also by numerous pegmatite veins and veinlets which vary from coarse to fine pegmatite, the minerals of the latter being only a little larger than the crystals of the granite. The deposits are worked by open cuts on a ledge of granite which trends eastward. The principal opening is 75 feet long and 15 feet wide and has a maximum depth of 20 feet. The pegmatite veins carry quartz, feldspar, molybdenite, apatite, biotite, chlorite, hornblende, and fluorite. At some places quartz and feldspar are graphically intergrown. Miarolitic cavities are found in both the granite and the pegmatite, and in the latter are lined with quartz crystals. The molybdenite occurs as scales and flakes from one-eighth inch to 1 inch in diameter; some of them are in cracks which join the pegmatite veins, others in the pegmatite veins themselves, and still others in the granite in positions which seem to have no connection with the pegmatite veins. Most of the molybdenite is in or within a few inches of the pegmatite, yet some of it seems to be an original constituent of the granite. There is little or no sericitization in the granite that carries molybdenite, and under the microscope the molybdenite is seen to inclose well-shaped crystals of albite and orthoclase, the corners of which are slightly rounded, indicating that the potash and soda feldspars were floated in the molybdenum sulphide solution and were partly dissolved before it solidified. The structure is much the same as that shown by some diabases where augite incloses idiomorphic feldspar, except that the corners of the feldspars in the ore have been rounded by corrasion. A photomicrograph of this ore is shown in Plate III, *B*.

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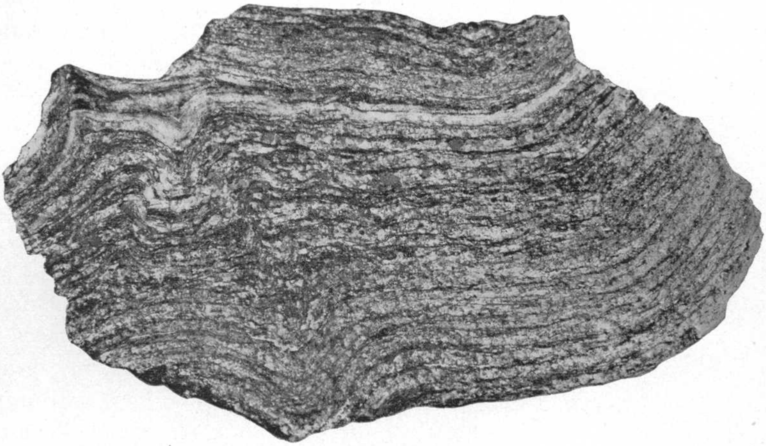
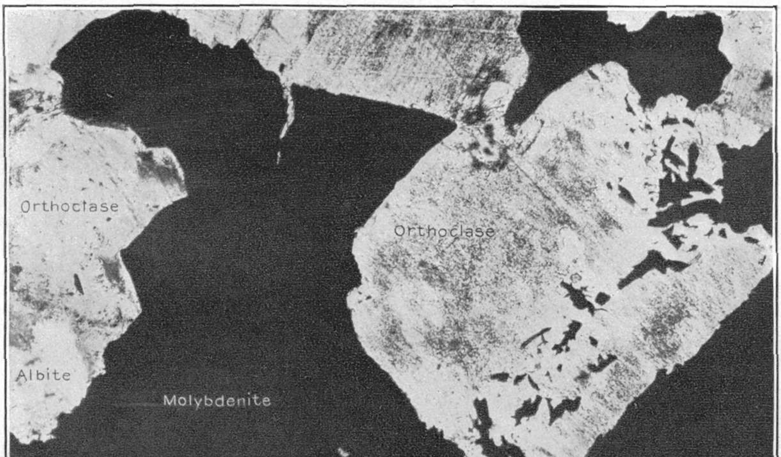
[a] Bull. U. S. Geol. Survey No. 340, 1908, pp. 234–235.



A. POLISHED SURFACE OF SCHISTOSE ORE OF MILAN MINE.



B. PHOTOMICROGRAPH OF MOLYBDENITE ORE FROM CATHERINE HILL.

WASHINGTON COUNTY.

GENERAL STATEMENT.

The geology of a portion of Washington County has been described by George Otis Smith and David White.[a] The eastern part of the county has been mapped by E. S. Bastin and will be described in a folio of the Geologic Atlas of the United States soon to be published. The western part of the county is made up in the main of slates and argillaceous schists. The zinc lode of Cherryfield is inclosed in these rocks, but so far as known there are no schistose deposits of pyritic copper ores in Washington County. East of this area of slates and schists is a broad belt of intruding granite which extends from Jonesport to Calais. Some deposits of molybdenite described by F. L. Hess[b] are associated with pegmatitic phases of the granite. East of this broad belt of granite, and including Pembroke, Lubec, and Eastport, is a large area of rhyolite, trap, and other volcanic rocks which are in part later than the granite. The Lubec lead mine, the Denbow Point silver deposit, and the copper deposits in Pembroke are associated with the basic phases of these volcanic rocks.

CHERRYFIELD MINE.

The Cherryfield mine, one-half mile east of Cherryfield, was first opened in 1878 and reopened in 1905. In 1909 it was under water. G. O. Smith visited the mine in 1907, and the following description is taken chiefly from his notes. The country rock is a dark aphanitic diabase, without conspicuous phenocrysts, and is composed of hornblende, feldspar, quartz, and magnetite; under the microscope it is seen to have a well-defined schistosity. Near the mine the dark schist is cut by unsheared diorite, and granite outcrops about three-fourths mile to the northwest. The deposit is a fissure vein which cuts the diabase, strikes N. 85° W., and dips steeply northward. A two-compartment shaft is sunk on the lode to a depth of 260 feet, and three short drifts are turned from this shaft. The vein is from 12 to 20 inches wide, is banded, and contains fragments of the country rock. The minerals are quartz, calcite, zinc blende, galena, pyrite, and chalcopyrite, and the ore is said to carry silver values. Chlorite is developed in the wall rock near the lode, but sericite is not conspicuous. No schistose ore was noted on the dump. A mill, erected in 1907, is equipped with crusher, rolls, trommel, jigs, and concentrating table. A high percentage of the selected ore is zinc blende.

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[a] Geology of the Perry Basin: Prof. Paper U. S. Geol. Survey No. 35, 1905.
[b] Bull. U. S. Geol. Survey No. 340, 1908, pp. 231–234.

LUBEC LEAD MINE.

The Lubec mine is located about 7 miles by wagon road from Lubec, on a shore marked by high, steep cliffs along which the veins outcrop. According to report the deposit was discovered in 1828 and has been worked in a small way through several short periods. A mill, now in ruins, is said to have been in operation for about six years in the late sixties and early seventies. A report on the mine by N. S. Manross is included in the report upon the natural history and geology of Maine for 1861 (p. 299). At present the mine is idle and the deep workings are submerged. A mill built in late years is equipped

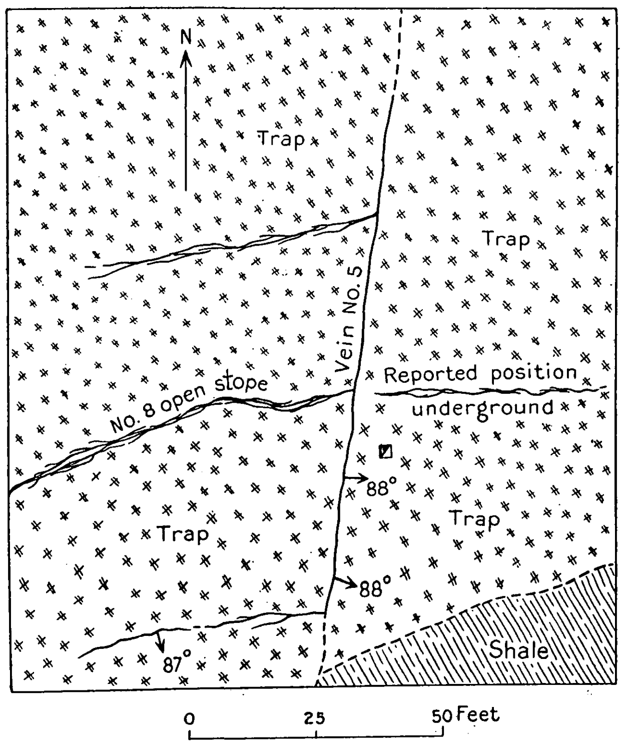

FIGURE 13.—Sketch showing position of principal veins in Lubec lead mine.

with jaw crusher, coarse and fine rolls, screens, jigs, a Wilfley table, and two Frue vanners. Steam power was used and the milling was done with salt water.

The country rock is a dense green trap—an altered surface lava. Near the mill the trap is in faulted contact with a dark fissile shale. The freshest specimens of the trap contain much secondary calcite, chlorite, and a little white mica. Near the lode and in the fragments which the ore includes chlorite appears to be more abundant than elsewhere, but sericite is not conspicuously developed.

The deposits are closely spaced intersecting fissure veins, some of which are shown in figure 13. The ore carries, besides lead and zinc, some silver, a little copper, and a trace of gold. The minerals are quartz, calcite, galena, zinc blende, pyrite, chalcopyrite, and limonite and manganese oxides. At many places the lodes are opened by short tunnels, deep cuts, and underhand stopes. Below the mill a shaft is sunk on the principal lode, but in 1909 this was under water. Above the mill this vein (No. 8), which strikes westward, is well exposed in the open cut, and considerable ore has been removed. It is a foot or more wide and carries galena. It consists of a number of thin, closely spaced, anastomosing fissures, between which are broken fragments of trap. Some of the stringers of galena play out as they pass into the country rock. The shaft sunk on this vein is reported to be 180 feet deep, and drifts are run out 170 feet under the bay. Vein No. 9 is east of No. 8, strikes N. 50° W., and would intersect No. 8 below the bay. Not far from the shore a 50-foot tunnel is driven in this deposit. Where exposed along the cliff the vein is a breccia zone 10 feet wide, with about 10 per cent of ore and gangue minerals in broken country rock. No. 5 vein, which strikes a few degrees east of north, crosses the other lodes, and for 80 feet along its strike forms a cliff escarpment 30 feet high. Along its face are thin flakes of sulphide ore. As shown by this vein, both sets of fractures, which are nearly at right angles to each other, were formed before mineralization. This is illustrated also in a small vein (No. 2) of quartz and galena, which strikes northeastward and ends in a crossing fissure in a small pit northeast of the mine. The galena and quartz follow the fissure for a few inches, making a large angle with their former course, as is indicated in figure 14.

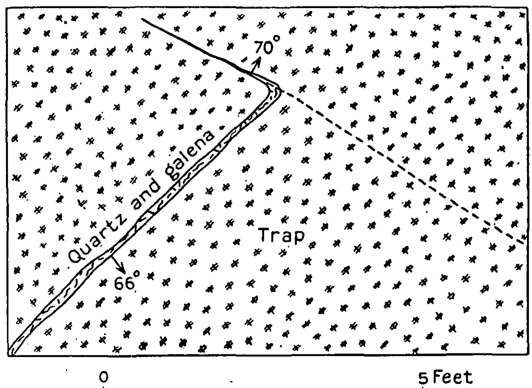

FIGURE 14.—Small vein in Lubec lead mine. The vein is later than the fissure in which it ends.

There are said to be thirteen veins in all, but some of those exposed at tide water to the south of the mill are very small.

DENBOW POINT MINE.

On Denbow Point a shaft is sunk in basic tuffs, but has been lost through caving. The country rock thrown up on the dump shows stringers of ore composed of quartz, zinc blende, galena, and pyrite.

PROSPECTS IN PEMBROKE.

On the road from West Pembroke to Ayres Junction, about 2 miles northwest of West Pembroke, there are several prospects in diabasic lavas. The most extensive workings are on the Sinclair farm, where the Eastern Exploration Company has recently been prospecting. The workings are all open cuts from 5 to 15 feet deep, and some of these are extensive. (See fig. 15.) The country rock is vesicular trap which, except for a little shearing at pit No. 5, shows no metamorphism. The ore occurs as veinlets filling fractured zones, as disseminations in vesicular lava, and as amygdaloidal fillings in the lava. There is some chloritization, but sericitization is not extensive. The minerals present are sphalerite, chalcopyrite, pyrite, galena, arsenopyrite, and bornite, with a little limonite near the surface and some small stains of malachite. The gangue is dolomite, calcite, and quartz, and at some places there is a noticeable amount of cherty silica. The dolomite, which is the most abundant mineral associated with the ore, is presumably ferruginous, since it is nearly everywhere stained with a brown film upon the weathered surface.

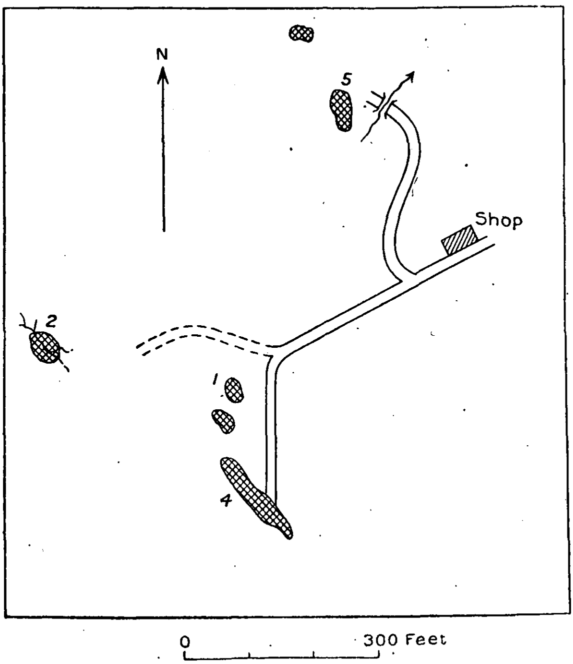

FIGURE 15.—Sketch showing position of pits of Eastern Exploration Company at Pembroke. By E. S. Bastin.

At pit No. 5, which is 120 yards northwest of the blacksmith shop, an excavation about 20 by 40 feet, sunk to a maximum depth of about 10 feet, has been made on a glaciated surface. The rock here is a bluish-gray amygdaloid, bleached white near the surface. Bands of dense gray flows alternate with the vesicular phases, the banding of the rock striking about southwest. The flows are cut by closely spaced parallel fractures which are nearly vertical and strike S. 55° W. There is a little shearing along some of these fissures as if they had resulted from compressive stresses. The amygdaloids are from one-eighth to one-half inch in diameter, and many are filled with pure white calcite, others are filled with calcite and quartz, and some of them are lined with shells of metallic sulphides with crystalline quartz inside. Some of the ore is in the sheared fractures and some is disseminated in the rock near the fractures. Most of the sulphides appear as small bodies not one-half inch in diameter, but some are in masses measuring 4 to 5 inches; zinc blende predominates. Fifty yards northwest of this pit a small cut shows banded comb quartz with zinc blende and galena.

At pit No. 2 the trap is traversed by small irregular fractures healed with quartz and sulphides. The relations are shown in figure 15. At pit No. 4, 200 yards southwest of the blacksmith shop, the country rock is darker than at pit No. 5 and some is porphyritic, but it is presumably a part of the same flow. The rock is cut by many thin stringers of metallic sulphides, galena and chalcopyrite being more abundant than at other pits. This pit is 125 feet long and 20 feet wide; its trend is S. 30° E., and most of the small stringers strike southwestward across it.

COOPER MINE.

Molybdenum deposits have been opened at Cooper, and the American Molybdenum Company has erected a mill there for treating the ore. The deposits have been described by George Otis Smith[a] and the following notes are abstracted from his report:

The country rock is granite, presumably of late Paleozoic age, and is cut by pegmatite dikes. In and near the dikes bunches of molybdenite crystals 1 to 2 inches in diameter are intimately mixed or intergrown with the quartz and feldspar of the pegmatite, where they were deposited by the pegmatite magma. They also occur in flakes and nests disseminated through the granite mass, especially near the pegmatite, where they may have consolidated from the granitic magma or may have been brought in by the pegmatite solutions, which are regarded as nearly contemporaneous with the granitic intrusion. The deposits were visited by F. L. Hess,[b] who reports that the molybdenite-bearing granite in the American Molybdenum Company's mine is shown by a trench and crosscut to be at least 300 feet long and 100 feet wide. Mr. Hess also reports that the Calais Molybdenite Mining Company, whose property joins the American Molybdenum Company's holdings on the north, has opened up similar deposits. Molybdenite has also been found near Sand Cove, Tunk Pond, and in the town of Brunswick, Cumberland County—at both places in the granite.

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[a] Bull. U. S. Geol. Survey No. 260, 1905, p. 17.

[b] Molybdenite in Maine, Utah, and California: Bull. U. S. Geol. Survey No. 340, 1908, p. 231.

SOMERSET AND OXFORD COUNTIES.

ROBINSON MINE.

The Robinson mine, in Concord Township, Somerset County, 7 miles southwest of Bingham and about 1½ miles north of Emden Pond, was discovered by W. S. Robinson in 1898 and has been worked now and then for several years. It is now owned by the Somerset Mining Company, which has erected a concentrator near the mine.

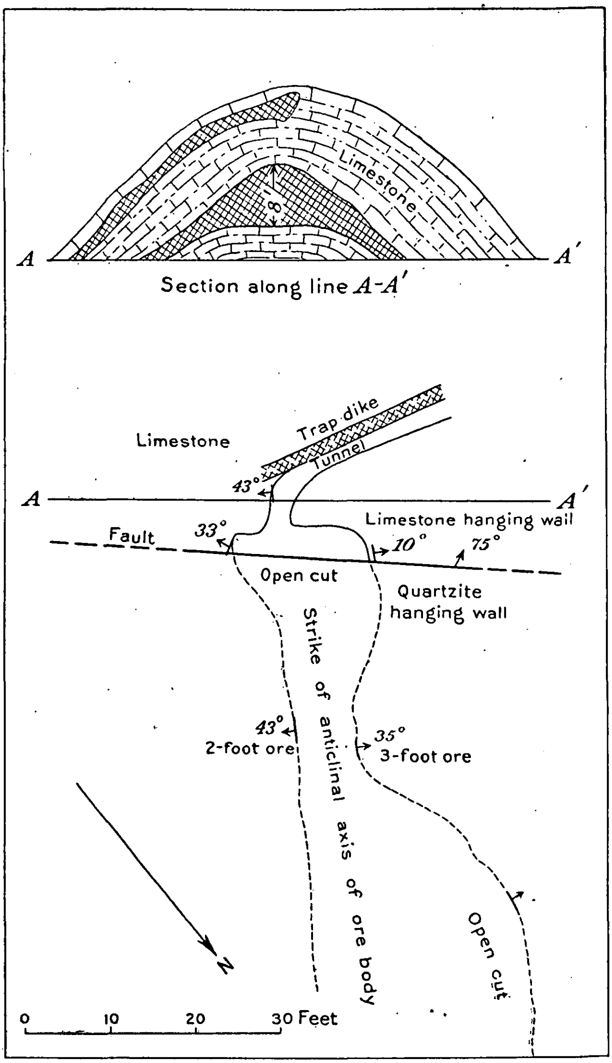

FIGURE 16.—Plan and cross section of the Robinson mine, near Concord, Somerset County.

This mill is equipped with a 12-inch Blake crusher, a set of rolls, a trommel, and three jigs. It employs steam power generated by wood and has a capacity of 10 tons daily. A small amount of concentrates and 8 carloads of ore have been shipped. The property has been idle since 1907.

The country is an area of quartzite, limestone, and shales, which are somewhat metamorphosed. These rocks are cut by trap dikes and probably by other intrusives. The quartzite consists of rounded quartz grains which under the microscope are seen to be rimmed with secondary silica. Between these grains biotite, chlorite, and hornblende have developed. As shown in figure 16, the deposit is a bedding-plane fissure which occupies the axis of an anticlinal fold. In thickness it varies from 2 to 8 feet and is thickest at the crest of the anticline, where it has been stoped or quarried out for about 60 feet along the strike of the crest and from 10 to 25 feet across it. At the southwest end of the open cut a fault strikes N. 50° W. and dips 75° SW. South of this fault the hanging wall of the deposit is sandy limestone overlain by shale; northeast of the fault it is quartzite. The fault is clearly older than the lode, for the lode crosses it without interruption. (See fig. 17.) A trap dike 6 inches wide, encountered on the southwest end of the cut, is followed in a tunnel some 15 feet. This dike rock is a very fresh basalt; even its olivines are but slightly altered, and it is clearly later than the ore body which it crosses.

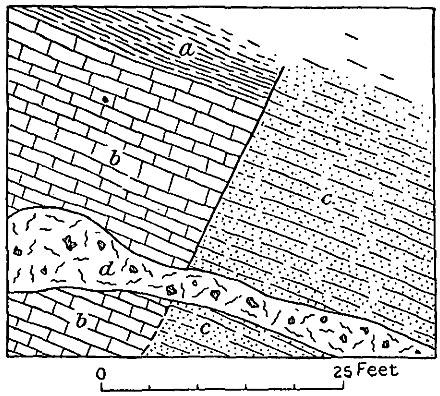

FIGURE 17.—Vertical section of wall at open cut, Robinson mine, near Concord, Somerset County. Faulting is older than ore deposition. *a*, Shale; *b*, limestone; *c*, quartzite; *d*, quartz and ore.

The gangue consists of quartz and dolomite. The metallic minerals are pyrite, galena, zinc blende, chalcopyrite, arsenopyrite, pyrrhotite, and a little bornite. The sulphides are said to carry silver. Much of the lode is barren white quartz, and the sulphides in the run of mine do not constitute more than 4 per cent of the mass, though in selected ore they run higher. The lode near the dike is quartz, with no metallic minerals. Just at the contact it is slightly oxidized and any metamorphic changes would be obscured, but an inch away it has suffered no visible change at the contact with the trap.

MOUNT GLINES.

The deposits at Mount Glines, in Oxford County, have been described in a paper by George Otis Smith,[a] from which are extracted the following notes:

At Milton plantation there are quartz veins in a gneissoid granite which is probably older than the granite quarried on the Maine coast. The principal lode is a well-defined fissure vein, with a maximum width of 4½ feet, composed of quartz and wall rock, the latter altered

[a] Bull. U. S. Geol. Survey No. 225, 1904, p. 81.

to kaolin and sericite. The ore minerals are pyrite and galena, which occur in bunches and bands up to 4 inches wide. The sulphide ores cross the structure of the quartz gangue and are presumably of later origin than the major portion of the quartz. Assays made by the Mount Glines Gold and Silver Mining Company are said to give good value in silver, copper, and lead, but these are presumably of picked specimens. A sample taken from the upper portion of the 35-foot shaft, where the vein is 2½ feet wide, and assayed by Dr. E. T. Allen, yielded less than $1 in combined metals.

MILAN MINE, NEW HAMPSHIRE.

GENERAL STATEMENT.

The Milan mine is in Coos County, northern New Hampshire, in the foothills of the Presidential Range, about 8 miles northwest of Berlin and one-fourth mile from the Grand Trunk Railway at Marston, with which it is connected by tramway. The deposit was discovered in the seventies and was worked steadily until 1886. According to Herbert J. Davis,[a] the monthly production was 2,600 tons, and this production was presumably sustained for several years. A 60-ton smelter was installed at the mine, but the fumes killed the spruce, and, owing to objections of the farmers and the decline in the price of copper, this was closed after a small tonnage had been put through. The property was opened again in 1895, when lessees mined about 1,500 tons of ore. It was acquired in 1907 by J. B. Carper, of Portland, who organized the Milan Mining and Milling Company, which is now working the mine and making regular shipments of ore and concentrates.

The deposit, first worked by open cuts, is operated through a 265-foot shaft inclined from 59° to 85° W. Levels are turned 70, 88, 115, and 215 feet (measured on the incline) below the collar; these aggregate about 1,500 feet.

The character of the deposit and its situation and accessibility to markets for all the products favor low costs both for mining and for milling. The stopes are at many places from 10 to 20 feet wide and the rock breaks well and runs easily in the chutes. Practically no timbering is required to hold the ground even when the large stopes are left open. The concentration of the ore is satisfactory for the pyrite, but the saving of copper, gold, and silver is low, and where these exceed a certain value it is found to be more profitable to ship the rock than to mill it. The ore is mined with air drills, dumped in a chute, and loaded in buckets of 1,200-pound capacity. It is hoisted to the top of the mill, where it falls over a grizzly, the fines going to a 1-inch shaking screen, from which they go over an elevator to the rolls. The coarse rock from this screen and from the grizzly passes over two picking belts on which the ore is washed

[a] Mineral Resources U. S. for 1885, U. S. Geol. Survey, 1886, p. 501.

by a small stream of water to facilitate cobbing. The waste from the picking belt is sent to the dump, the low-grade pyrite ore is run through the mill, and the ore carrying a noticeable amount of copper is shipped to smelters. The milling ore goes through a Dodge crusher and is elevated to the ore bin, from which it passes through coarse rolls, up an elevator through an impact screen of one-eighth inch mesh. From this screen the fines go to a thickening tank and pass to a Richards pulsator classifier, where they are classified for the two Wilfley and three Bartlett tables. The coarse material from the screen goes through fine crushing rolls and is elevated back to the shaking screen. The mill feed carries about 26.5 per cent sulphur and 1.35 per cent copper. The concentration is 2 or 3 to 1 and the concentrates are shipped to acid works, from which the cinders are sold to smelters and smelted for the copper, gold, and silver. Analyses of representative concentrates and cobbed ores are given below:

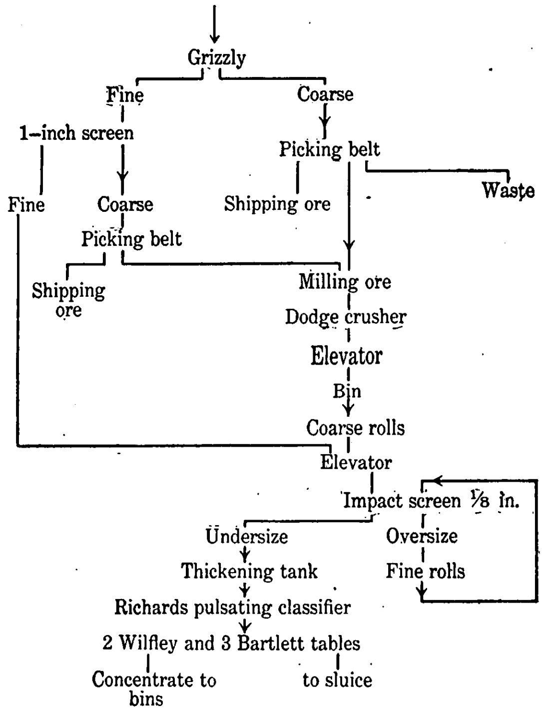

FIGURE 18.—Plan of ore treatment at Milan mine, New Hampshire.

Analysis of concentrates from Milan mine.

[Chas. L. Constant, analyst.]

	Ounces per ton.
Gold	0.21
Silver	1.50
	Per cent.
Copper	1.58
Arsenic	None.
Sulphur	41.30
Silica	12.47
Alumina	2.80
Iron	35.00
Lime	Trace.
Magnesia	0.30
Zinc	6.46

Analysis of shipping ore cobbed from the mine run.

	Per cent.
Insoluble	15.40
Sulphur	39.84
Copper	2.25
Zinc	7.26
Lead	1.57
Iron	32.85

The ore carries about $1.50 in gold and 1 or 2 ounces in silver to the ton, and the sulphur, iron, copper, gold, and silver yield from $12 to $18 a ton. There is a considerable accumulation of tailings from former operations which carry 36 per cent of sulphur and 1 per cent of copper, and these are now being put through the mill for their pyrite content. From the low copper content of the concentrates it appears that a high percentage of the copper passes off in the slimes.

GEOLOGY.

The Milan area is included in the great shield of crystalline schists which covers most of New England and which is generally regarded as of pre-Cambrian age. These schists have been intruded presumably in Paleozoic time by great masses of granitic rocks which show little or no deformation by shearing and are therefore later than the regional metamorphism of the schists. To the east and south these rocks cover extensive areas, but they are not known to be present in the vicinity of the mine.

The geology of New Hampshire has been mapped and the rocks described by C. H. Hitchcock.[a] In the geologic atlas accompanying his report the rocks inclosing the copper deposits are mapped as the Lyman group, a belt of which 3 or 4 miles wide extends from a point 2 miles south of the Milan mine northward toward the Canadian boundary. A belt of the same rocks separated from the first by intruding porphyry extends southwestward 50 miles or more beyond Woodville. The latter belt includes the mines of the Ammonoosuc district, which have been worked for copper, gold, and silver. The deposits of these mines, to judge from the descriptions of the ores, have many features in common with the deposits at Milan.

The rocks mapped by Hitchcock as the Lyman group are mainly quartzites and siliceous chloritic schists, which were regarded by him as upper Huronian. They are in the main siliceous sedimentary rocks intensely metamorphosed. On either side of this belt are areas equally long and wider, which Hitchcock mapped as the Lisbon group. These two groups of rocks are intimately interfolded and

[a] Geology of New Hampshire, vols. 1 to 3.

presumably have about the same age and origin. Southeast of the Milan mine, including the area of the Milan Hills and extending southward beyond Berlin, is an area mapped by Hitchcock as "Lake and Granitic gneiss." The contact relations with the Huronian rocks are not given, but this gneiss is presumably in part a regionally metamorphosed granite, the age of which is not known.

The top of the Huronian series is the auriferous conglomerate which is exposed at many places in New Hampshire. It contains pebbles of jasper, schists, and quartz and has been greatly metamorphosed. It carries locally from 40 cents to $2 a ton in gold, but it is not clear whether the gold is a clastic constituent or was introduced after the formation was deposited; the presence of quartz pebbles, however, suggests the possibility of mineralization prior to regional metamorphism.

The country rock at the mine is a highly metamorphosed siliceous schist. In the underground workings, which do not go far into the country rock, it shows neither quartzites, limestones, or conglomerate layers, nor grains of grit, bedding planes, or other characteristics of sedimentary rocks that would indicate its clastic character. It has well-defined planes of schistosity, which near the mine strike northward and dip from 30° W. to 90°. Locally they dip eastward at very high angles. The microscope shows the schist to be composed of quartz, chlorite, biotite, muscovite, and pyrite. The quartz grains are oriented parallel to the mica and chlorite flakes.

On the surface, perhaps one-fourth mile northwest of the mine and between the mine and the railroad track, beds of highly siliceous schist outcrop at many places. Some of these rocks contain a myriad of thin dark actinolite fibers. Where subjected to weathering the siliceous schist shows the rounded sand grains of a fine quartzite. The wall rock of the mine is less siliceous than the quartzite and contains a greater percentage of chlorite, biotite, and muscovite. Mineralogically the wall rock is such as may have resulted from the intense regional metamorphism of a quartz-rich shale or clayey quartzite, and there is nothing inconsistent with a sedimentary origin in its general appearance and mineralogical composition.

J. W. Huntington,[a] of the New Hampshire Geological Survey, describing the area near Milan, says:

> The railway cuts the gray siliceous schist in the east part of Stark, in the corner of Dummer, and at several places for a mile east of West Milan. Easterly dips prevail on the west and westerly dips prevail on the east, so as a whole it seems to be a synclinal axis with minor folds near the middle of the area. The rocks, except the hard siliceous schists on the west, we have placed in the Lyman group, which is the upper member of the Huronian.

[a] Hitchcock, C. H., Geology of New Hampshire, vol. 2, 1877, p. 201.

From these observations it seems that the Milan mine is on the east limb of the synclinal axis formed by the schistosity. A cross section taken from the New Hampshire atlas is shown as figure 19.

On the 115-foot level of the mine, about 35 feet northwest of the shaft, there is about 3 feet of an actinolitic schist which is different in appearance and mineralogical composition from the biotite schist that constitutes the walls at most places. It consists of a dark, fine-grained groundmass containing abundant crystals of hornblende about 1 mm. thick and 1 cm. long. Under the microscope the horn-

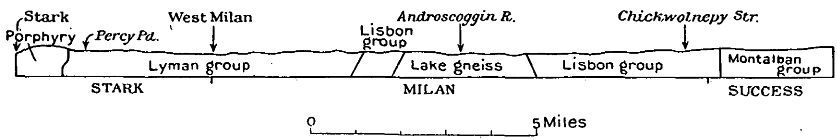

FIGURE 19.—Geologic east-west cross section through West Milan, N. H., north of the Milan copper mine. (After Hitchcock, Atlas of New Hampshire, 1878.)

blende shows characteristic cleavage and is surrounded by a groundmass of fine quartz and clouded sericitic bodies, which are probably decomposed feldspars. It contains also some chlorite, magnetite, and calcite. This rock appears to be more basic than the biotite schist and, to judge from its relations with the schist, it is probably the metamorphosed product of a dike of diabasic or more acidic composition—a dike which cut the siliceous country rock before that rock was metamorphosed.

MINERALS OF THE ORE.

The deposits are overlapping pyritic lenses parallel to the schistosity of the country rock. The gangue is quartz, chlorite, black mica, and white mica. The sulphides are pyrite, chalcopyrite, zinc blende, galena, bornite, and chalcocite. Little or no magnetite is present and pyrrhotite was not noted in several tests that were made. In a list of minerals of New Hampshire, published in 1886,[a] however, it is mentioned as occurring in the ore. The ore carries $1.50 in gold and about 1 ounce of silver to the ton. Much of the ore is solid pyrite, which includes fragments of the banded schists oriented parallel to the walls. Here and there the pyrite is cut by white quartz stringers, as is

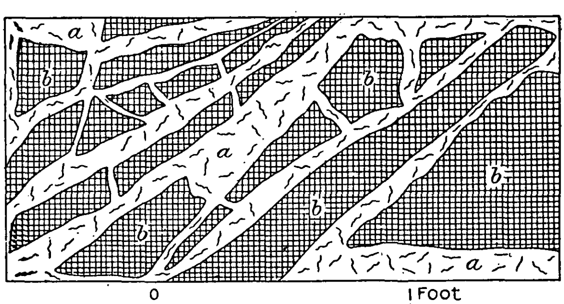

FIGURE 20.—Pyrite cut by quartz, Milan mine. *a*, Quartz; *b*, pyrite.

[a] Mineral Resources U. S. for 1885, U. S. Geol. Survey, 1886, p. 757.

shown in figure 20. Some of the sulphide ore, notably in the crosscut to the west at the south end of the 115-foot level, is massive zinc blende, carrying well-formed crystals of pyrite 1 mm. in diameter, with here and there small specks of galena. In the stope at the north end of the 115-foot level and between the 115-foot level and the 70-foot level above the main ore body, a mass of white quartz is cut by veinlets of galena and pyrite and has specks of those minerals scattered through it. Below this ore the vein consists of pyrite and chalcopyrite cut by innumerable fracture planes which are filled with paper-thin films of chalcocite, the whole carrying 12 per cent of copper. An oxidized seam with 6 inches of limonitic material is above this body of copper ore, and this appears to have been a watercourse which was followed by the downward circulation of sulphate waters which deposited chalcocite and bornite films on the chalcopyrite. This ore, which carries more of the primary chalcopyrite than the mine run, is also richer in gold. Some of it carries as much as one-fourth ounce to the ton. A cross section of the vein at this place

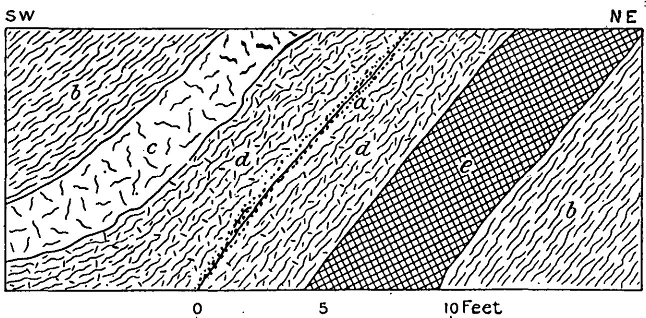

FIGURE 21.—Section of vein at east end of 115-foot level, 40 feet above floor, Milan mine. *a*, Oxidized streak; *b*, schist; *c*, massive quartz, pyrite, and galena; *d*, pyritiferous schist or milling ore; *e*, massive pyrite.

is shown in figure 21. The lode is at no place completely oxidized, but in the stopes 40 feet below the surface limonite in seams and copper carbonate and sulphate were noted at many places along narrow fractures. Locally the sulphide ore extends to the grass roots, with only a light veneer a fraction of an inch thick where it is exposed to the air.

ORE BODIES.

The ore bodies are two overlapping lenses separated by 10 or 15 feet of biotite schist. They strike a few degrees east of north and dip steeply westward. They are not tabular but broadly they approach that form. In detail, however, they are characterized by gentle undulations along both the dip and the strike and at some places there are turns of more than 45° along both dip and strike. The south ore body outcropped on the present site of the mill and the mine was first worked in an open cut from 15 to 25 feet wide, which extends 200 feet along the strike. At a depth of 70 feet a shaft was sunk and stopes in both ore bodies were carried up to that level. The south ore body as developed is from 5 to 25 feet wide and like the north ore body it dips steeply westward. Near the surface it is developed southward for 275 feet along the strike. At its northern termination the end of the ore pitches southward at a low angle. On the 70-foot level it is 45 feet from the shaft and dips toward it from 50° to 70°, becoming steeper in depth. Near the end of this lens, at the pump station below the 115-foot level, the ore is highly crumpled.

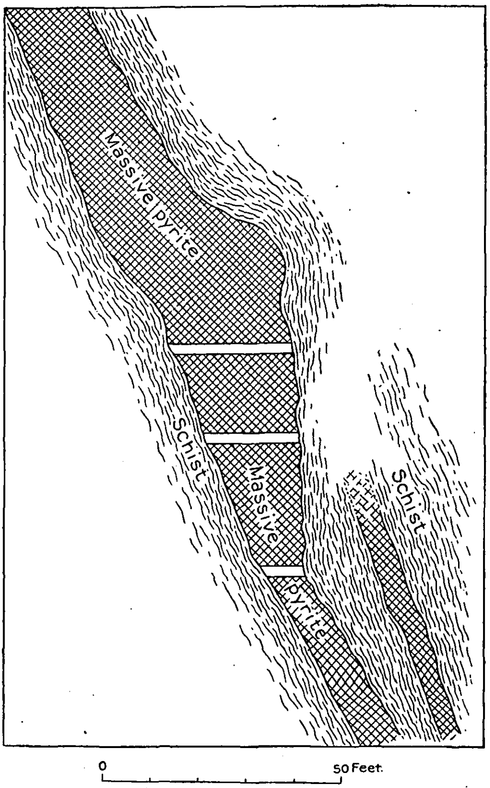

FIGURE 22.—Cross section of ore bodies, Milan mine.

The north ore body is developed northward 550 feet along the strike and it is approximately 15 feet wide. The south end of the north ore body on the 115-foot level is encountered in a short crosscut, 40 feet southwest of the shaft. It has been followed N. 20° E. for a distance of 360 feet, where it bends to due north, keeping the course for 120 feet. At chute No. 2 it turns at an angle of 40°, striking N. 40° E. for 75 feet. A cross section of the two ore bodies 35 feet south of the shaft is shown in figure 22, and a plan of the 115-foot level in figure 23.

From a point near the east end of the 115-foot level and about 40 feet up in the stope the section of the lode, which here dips 40° NW., shows 4 feet of massive pyrite above a foot wall of chloritic quartz schist. Above this is 6 feet of pyrite and quartz with a little mica, all highly schistose, the planes following the orientation of the lode. Above the latter is a mass of quartz about 3 feet thick, with seams of pyrite and galena. Near the center of the 6 feet of pyrite and quartz which constitute a milling ore there is a seam of highly oxidized ore along a plane of movement. This plane is clearly a postmineral fissure. A few feet lower this fissure departs from the ore body, keeping its regular course while the ore body turns, striking nearly northeastward and dipping steeply. Where noted in a drift below it is vertical and at one place overturned.

The ore bodies are parallel to the schistosity. At some places the walls are intensely crumpled and much of the milling ore consists of the thin alternating bands of schist and pyrite intimately interbanded and crenulated. These seams of pyrite and quartz are also parallel to the schistosity, and as shown by Plate III, *A*, are clearly metamorphosed by the same crumpling movements. The ore is undoubtedly older than the metamorphism of the schists. At many places it grades into the pure massive pyrite ore, but the latter does not show any schistosity. There is no noticeable sericitization or other hydrothermal metamorphism of the walls nor any leaching of the wall rock, such as is characteristic of most ore bodies not regionally metamorphosed, and the ore at no place shows comb structure, crustification, or druses.

The plan of the 115-foot level illustrates further the effects on the ore body of the regional metamorphism due to intense shearing movements under load which develop the schistose structure in the country rock. Before shearing the ore body was probably a single tabular mass, but by these movements it was thrust endwise upon itself, so that it divided and overlapped. The division can hardly be called a fault in the common sense, since it took place in the zone of flow for the schist and was a pulling apart, not

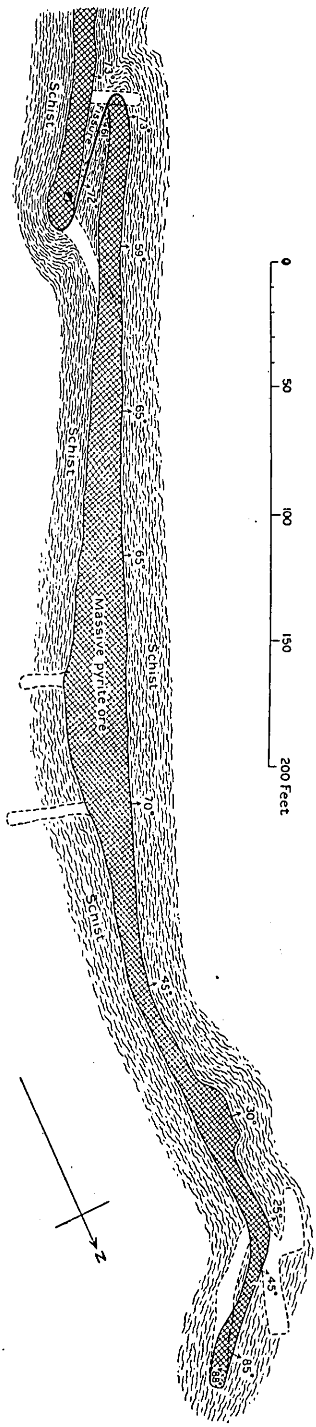

FIGURE 23.—Plan of 115-foot level, Milan mine.

by a sharp cleavage, but rather as a somewhat viscous body is divided. A tight fissure dipping westward at about the same angle as the two ore bodies joins the two ends and wraps around the ore at both terminations. The schistosity likewise wraps around the ends of these ore bodies and parallels the fissure which joins them. These features are shown in figure 23. This relationship of the schistosity to the line of movement which separates the two lenses shows that the ore body has been subjected to the same earth movements as the rock. Since it has separated in the zone of flow it must have been deposited before regional metamorphism. This is further indicated by the gradation of the massive pyrite ore into pyrite containing parallel quartz and mica bands, of this into quartz biotite with numerous thin bands of pyrite, and of this, again, into schist with only an occasional band of pyrite and this into nearly pure schist. Thus the rock shows bands of the schist and bands of the pyrite varying in all proportions along the wall, and the ore always shows the minutely schistose structure wherever it contains quartz and biotite. The main lode of pyrite ore has exactly the same character as the smaller massive layers and must have the same origin, but where pure and large it is as free from conspicuous marks denoting movement as any ore deposit in unmetamorphosed rock. Some of the crystals of pyrite have perfect form when included as the thinnest seams between the quartz-rich or biotite-rich layers of the schist. As these pyrite seams increase in size and purity they become more massive, and where silica minerals are absent the ore does not show any lamination parallel to the schistosity of the country rock, although the ore is, without doubt, older than the final metamorphism of the schist and partook in its movements. The aluminous, more or less plastic wall rock was capable of crumpling to gnarly schistose layers, and where the seams of pyrite alternate with thin seams of quartz the same schistosity is shown; but massive pyrite ore not containing quartz or clayey material adjusts itself to conditions of pressure without leaving a conspicuous record of the movements. The pure pyrite is at no place laminated. The larger pyrite bodies have broken and have been recemented by pyrite and the smaller crystals have completely recrystallized, mainly into small cubic and octahedral crystals rather than into pyritohedrons.

Galena and zinc blende have also recrystallized. Some of the chalcopyrite shows faint lamination, a feature of chalcopyrite noted also in the Tapley mine at Brooksville, Me.

The ore bodies are believed to be tabular deposits of sulphide ore metamorphosed by the same movements that converted the highly quartzose shales into quartz-biotite schists. It is remarkable that this lode, like most of the members of the class, should everywhere be approximately parallel with the schistosity of the country rock. Ore bodies in a given district of unmetamorphic rocks very often present a great variety of dips and strikes, and in many districts there are two vein systems nearly at right angles to each other. The movement causing the schistosity is apparently controlled to some extent by the ore bodies or else the ore bodies are rotated to conform to the general movements as recorded in the structure of the schists. Probably the agreement of ore with schistosity is brought about in both ways. First, the pyrite bodies are broken and the parts tend to orient themselves at right angles to the line of pressure, as, for example, the flat or oblong grains of sand in a quartzite or quartz schist, or as the mica flake in a mica schist; and, second, the schistosity of the walls is probably controlled locally by the large masses of ore if the ore body is too immobile to orient itself to conform with new conditions of pressure as do the oblong quartz particles in the quartzose shale when it is metamorphosed to biotite schist.

At the south end of the north ore body on the 115-foot level the ore is highly siliceous and consists of intensely crumpled pyrite and quartz. At this place, where the ore body pulled apart and became two lenses, the ore looks like a surface of gnarled oak or vermicelli. Here the schistosity of the walls instead of striking northward parallel to the main lode strikes westward parallel to the end of the lens. On an intermediate level, just below, near the pump station, the same intense crumpling is shown at the north end of the south ore body.

These places show that the ore body broke where it was most siliceous and most heterogeneous and because of that heterogeneity of composition the movement was best recorded. If it had been pure pryite instead of quartz-pyrite-chlorite ore it would not have shown the intense crumpling, for the pyrite would have broken and recemented into an apparently homogeneous mass. Since the broken end of the south ore body pitches toward the south, with the ore on the foot wall of the pitch, it should be expected that the broken end of the north ore body should also pitch to the south, with the ore on the hanging wall of the pitch.

SUMMARY OF THE GENESIS.

The deposit was at one time a large mass of ore contained in impure quartzite or slate which if metamorphosed was less intensely metamorphosed than at the present time. The ore may have been deposited at the time the granular rocks mapped by Hitchcock as "Lake and Granitic gneiss" were erupted or at the time of the intrusion of a basic igneous rock which is now actinolite schist. It was not, however, a contact-metamorphic deposit, for it has none of the characteristics of such deposits and it does not contain garnet and epidote and other lime silicates which are usually found in such deposits. Presumably it was first formed at moderate depth and then consisted of quartz, pyrite, zinc blende, galena, chalcopyrite, and some aluminous material—either clay or sericite; the walls were presumably replaced by pyrite and other minerals. After deposition it was deeply buried and was intensely deformed in the zone of flow at the time when the siliceous shales were subjected to regional metamorphism and changed to schists, or at the latest before this process had ceased to operate. During the process of metamorphism the deposit was deformed by pressure. Certainly it was pulled apart at one place and thrust back on itself so that the two ends overlapped some 40 feet. The ore body pulled apart where it was most siliceous, where parallel sheets of quartz and mica are abundant in the pyrite, and because of this circumstance of heterogeneity also a maximum of squeezing and crumpling was recorded. The sulphides were crushed, recemented, and at some places dissolved and reprecipitated. Drusy cavities and banded and comb structures, if present, were destroyed. Any evidences of hydrothermal metamorphism along the walls of the deposit were obscured by the subsequent regional metamorphism of the deposit and the country rock. After metamorphism the rock above the deposit, probably a considerable thickness, was eroded away, and minor movements resulted in fractures and slickensided planes, cutting the lode approximately parallel to the dip and strike. Ultimately through water and glacial erosion the present outcrop of the deposit was exposed. Descending sulphate waters deposited a little chalcocite in the later fractures. The lode was partly oxidized at the outcrop, but at most places the oxides did not extend more than 40 feet below the surface and at some places near the surface they scarcely formed at all.

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