Economic Geology, v. 16, pp. 1-36

ECONOMIC GEOLOGY

WITH WHICH IS INCORPORATED

THE AMERICAN GEOLOGIST

VOL. XVI. JANUARY, 1921. NO. 1

THE LIMESTONE ORES OF MANHATTAN, NEVADA.

HENRY G. FERGUSON.[1]

INTRODUCTION.

Most of the ore deposits of the Manhattan district are gold-bearing veins of a simple type and present no unusual features, but other ores inclosed in a single thin bed of limestone offer interesting problems.

Manhattan is situated in the southern part of the northeasterly trending Toquima Range, about 35 miles north of Tonopah. The Toquima Range is one of the less prominent of the many narrow, isolated mountain ranges which are such notable features of the Great Basin topography. The range is bordered by desert valleys—Ralston Valley and Monitor Valley on the east and Big Smoky Valley on the west. On both sides, but particularly on the west, the boundary between rock in place and valley fill is irregular, in marked contrast to the sharp lines of demarcation on the eastern front of the Toyabe Range, which borders Big Smoky Valley on the west.

The district was first visited by the writer in the summer of 1915. At that time lode mining had suffered a collapse and little could be seen of the ore deposits. Work, therefore, was chiefly directed to a study of the complexities of the geologic structure

[1] Published by permission of the Director, U. S. Geological Survey.

and observations on the placers.[2] The district was revisited in 1919 and the geology of the principal deposits studied in some detail; another short visit made in June, 1920. The writer desires to acknowledge the courtesies extended to him by all the mining men of the district. The detailed geologic maps of the surface geology and underground workings of the White Caps mine, made by Messrs. O. McCraney and J. L. Dynan, were of especial value. The writer gratefully acknowledges the assistance in criticisms and helpful suggestions from his colleagues, particularly A. C. Spencer and W. T. Schaller.

The ore deposits of the present Manhattan district date from April, 1905, when "specimen ore" was discovered by John C. Humphrey on April Fool Hill. An old mine about 4 miles south of the present town of Manhattan had, however, been worked in the late sixties. The discoveries of rich surface ore with plentiful free gold were made within a few hundred feet of the road leading west from the old camp at Belmont. That such ore should be passed unnoticed for 40 years must be attributed to the inconspicuous croppings which characterize the later discovered deposits.

During 1906 the district was in a state of excitement and rich discoveries were constantly being reported. The winter of 1907–8 was marked by depression following the deflation of the boom, but the hard times, which led to temporary cessation of quartz mining, turned the attention of the miners to the placers of Manhattan Gulch. For several years lode mining was conducted spasmodically, and generally the placer output exceeded that of the lode mines. The best placer ground has, however, been exhausted since 1915, and since that time the lode output has been the more important. In 1917 the discovery of rich ore in the lower levels of the White Caps mine led to another boom, which, though short lived, led to a considerable amount of exploratory work. At the present time a small amount of

[2] Ferguson. H. G., "Placer Deposits of the Manhattan District, Nevada," U. S. Geol. Survey Bull. 640, pp. 163–193, 1917.

exploration work is being carried on, but the production is principally from the shallow surface workings of lessees.

GENERAL GEOLOGY.

The rocks of the southern portion of the Toquima Range include Paleozoic sediments, intrusive granodiorite masses of Cre-

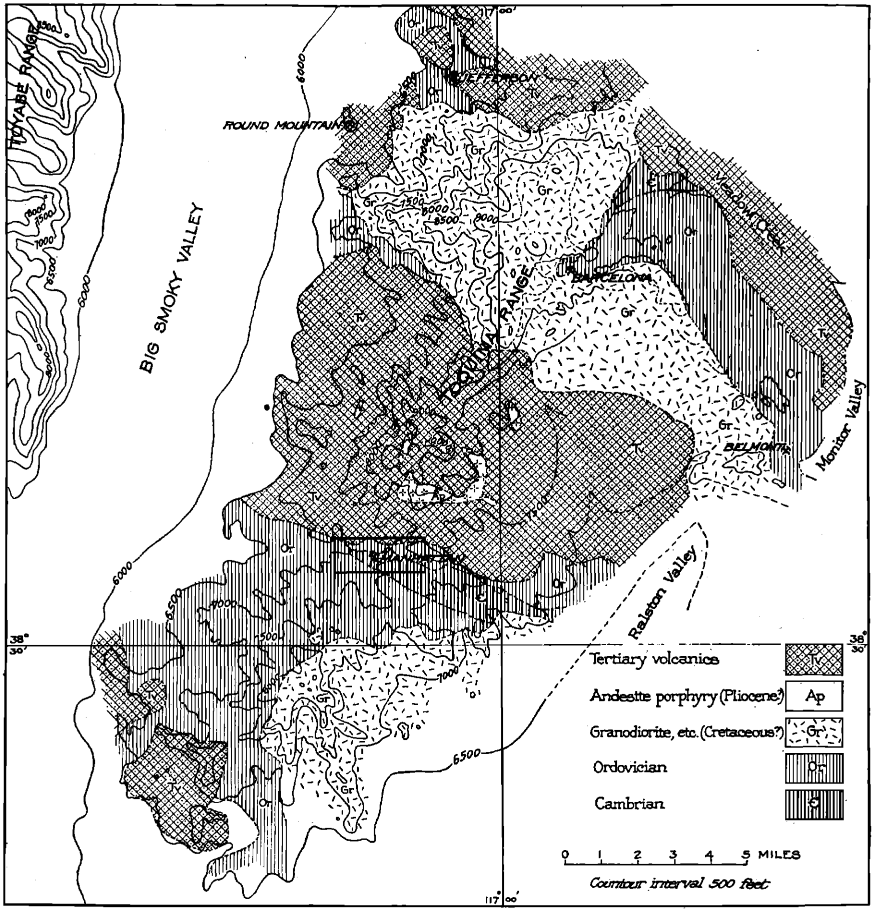


FIG. 1. Geologic map of the southern part of the Toquima Range.

taceous or Eocene age and Tertiary lavas and sediments and intrusives. In the productive portion of the Manhattan district (fig. 2) the older sediments are of Cambrian or Ordovician age, intensely folded, cut by many faults and everywhere more or less metamorphosed.

Paleozoic Sediments.—The Cambrian sediments, in which are the productive ore bodies, consist principally of micaceous schists. Lenticular beds of white quartzite and dark fine-grained sandstone are common. There are also several limestone beds, of which three in the lower part of the formation, and two near its top are sufficiently well defined to be traced on the surface. Other smaller beds are less persistent. Since many of the deposits occur as replacements in limestone, these beds have been well exposed by prospecting, and consequently the structure of this part of the district could be worked out in detail.

The three lower beds are but slightly altered and consist of blue-gray or white, fine-grained crystalline limestone. The lowest, locally known as the Pine Nut limestone, is about 10 feet thick and is the only one which shows any development of silicate minerals, and that only in scattered nodules. The next, known as the Morning Glory limestone, is 15 to 20 feet thick and consists of pure crystalline limestone. The third bed, the White Caps limestone, is 30 to 35 feet thick and forms the wall rock of some of the most important deposits of the region. Except where altered by mineralizing solutions, it is a pure crystalline limestone, light blue in color and essentially free from silicates. The two limestones in the upper part of the Cambrian terrane, on the other hand, show a considerable development of silicates and range from white crystalline limestones to rocks consisting essentially of diopside. The total thickness of Cambrian sediments exposed in the district probably exceeds 3,000 feet.

Above the Cambrian and tentatively assigned to the Ordovician is a fine-grained dark schist, about 400 feet thick. Above the dark schists is a series composed principally of a dark-gray thin-bedded limestone, associated with which are varying amounts of black jasper. This series is probably less than 400 feet thick.

The first fossiliferous horizon is found above this dark limestone. There are lenticular beds of dark quartzite, overlain by a few feet of slates carrying well-preserved graptolites, indicating a horizon equivalent to a part of the upper Pogonip formation of the Eureka district[3] and to the Palmetto formation of the Silver Peak quadrangle.[4] Above this is a dark jaspery limestone, a few feet in thickness, identical in character with that below the quartzite. Above this is a considerable thickness of chloritic schist similar to that found directly above the Cambrian, but here diversified by occasional beds of impure brown limestone and dark blocky slate.

An isolated outcrop of Carboniferous (Pennsylvanian) sandstone was found about a mile northwest of Manhattan. The relations to the other sediments are undetermined.

Granitic Rocks.—Large masses of granitic rocks occupy a considerable area in the Toquima range. The rock is in general coarsely porhpyritic, with numerous orthoclase phenocrysts, up to a couple of inches in length. Microscopic examination shows that it ranges in composition from a soda-granite to a granodiorite, more commonly the latter. There are also many dikes of very fine-grained aplite. These consist essentially of quartz and orthoclase with varying amounts of muscovite and a small amount of pyrite, apparently original. In places quartzose segregations in the aplites form a connecting link with the quartz veins. Spurr[5] describes an occurrence in the nearby Belmont district, in which an aplite dike grades into a metalliferous quartz vein.

The nearest large exposure of granitic rock lies about 2 miles to the south of the productive mines. But it is probable that there is a nearer granite mass to the north, beneath the Tertiary lavas, since pebbles of granite are common in the lower rhyolite

[3] Walcott, C. D., Mon. U. S. Geol. Survey, vol. 8, p. 284, 1884.
Hague, A., Mon. U. S. Geol. Survey, vol. 20, p. 58, 1892.
Spurr, J. E., Bull. U. S. Geol. Survey No. 208, p. 91, 1903.

[4] Turner, H. W., "A Sketch of the Historical Geology of Esmeralda County, Nev.," *Amer. Geologist,* vol. 29, p. 265, 1902.

[5] Spurr, J. E., "Quartz Muscovite Rock from Belmont, Nevada," *Am. Jour. Sci.,* 4th Ser., vol. 10, p. 351, 1900.

breccias, and the Ordovician limestones on Salisbury Hill just south of the lava-covered area and show intense contact metamorphism. There is, however, a small dike of coarse muscovite granite grading into aplite, about 1,500 feet northeast of the White Caps mine, and two small masses of a much altered aplitic rock have been cut on the 800-foot level of the White Caps.

The age of the granodiorite is probably late Cretaceous or early Tertiary, though no conclusive data can be obtained in this range. Although the granitic intrusion probably closely followed the mountain-building movements which produced the intense folding, there is no evidence of any direct association. The major folds had been developed before the rise of the intrusive to the level of the present surface, for the granodiorite cuts the folded rocks at all angles and shows no sign of any gneissic structure or even of important shearing. There is no evidence of doming of the sediments by the intrusive.

The rim of intense metamorphism surrounding the granite is narrow. The limestones close to the contact are epidotized and abundant biotite is developed in the schists. The more distant effects are shown in the development of silicate minerals, particularly diopside, in some of the limestones and the presence of small knots of silicates in the Ordovician schists.

Tertiary Rocks.—The Tertiary rocks lie to the north of the productive part of the district and consist predominantly of rhyolite. The earliest is a breccia composed of angular fragments of the older rocks without volcanic material. Rhyolite braccias containing fragments of the underlying sediments form a large part of the effusive rocks. The lower breccias are cut by irregular intrusions of a fine-grained rhyolite. Near the top of the Tertiary series is a considerable thickness of shale, fine-grained sandstone, water-laid tuff, and conglomerate. The finer grained phases of this resemble very closely the Siebert tuffs of the Tonopah district considered to be of late Miocene age. Above this comes another series of rhyolite breccias. Following this there was intruded a considerable mass of rather coarse andesite porphyry. The principal body of this rock lies about 2 miles to the northeast of the White Caps mine and numerous smaller masses and dikes occur throughout the region. The principal intrusive mass appears to be laccolithic in nature and has tilted and wedged apart the tuffs and breccias which it intrudes.

Structure.—The Paleozoic rocks are compressed into close folds in part overturned toward the north. The axes of the major folds trend a few degrees to west of north, at right angles to the present trend of the Toquima range. The principal anticline is cut off obliquely on its northern side by an overthrust fault which brings the Cambrian above the Ordovician schists and limestone. The overthrust dips to the south and southwest at from 36° to 70°, and was undoubtedly formed at the time of folding of the sediments through the irregularities of its plane may be in part due to later faulting and tilting. A normal fault along the southern border of the Cambrian schists may also date from this period, since it is cut by later faults trending in an opposite direction.

As may be seen from the detailed geologic maps (Figs. 2 and 3), the productive part of the region is cut by a large number of small normal faults. These could be mapped with certainty only in the portion of the territory traversed by the Cambrian limestone. In one instance, a small dike of alaskite appears to occupy a fault plane. Two of the faults were traced to the northward across Salisbury Mountain. On the northern slope of the mountain the contact between the Ordovician and the Tertiary breccia follows the strike of one of these faults, so it is to be presumed that faulting was of Tertiary age. The field relations, however, do not preclude the possibility that the breccia was deposited against a pre-Tertiary fault scarp. The faults are roughly parallel, for the most part varying in strike from a few degrees east of north to about east-northeast, and there is a tendency for those of more northerly strike to be cut off by those trending to the eastward. This intense normal faulting is confined to the productive portion of the district. Numerous small faults are, however, observable in the vicinity of the prospects in the lavas on Bald Mountain, 3 miles to the north. There are also normal

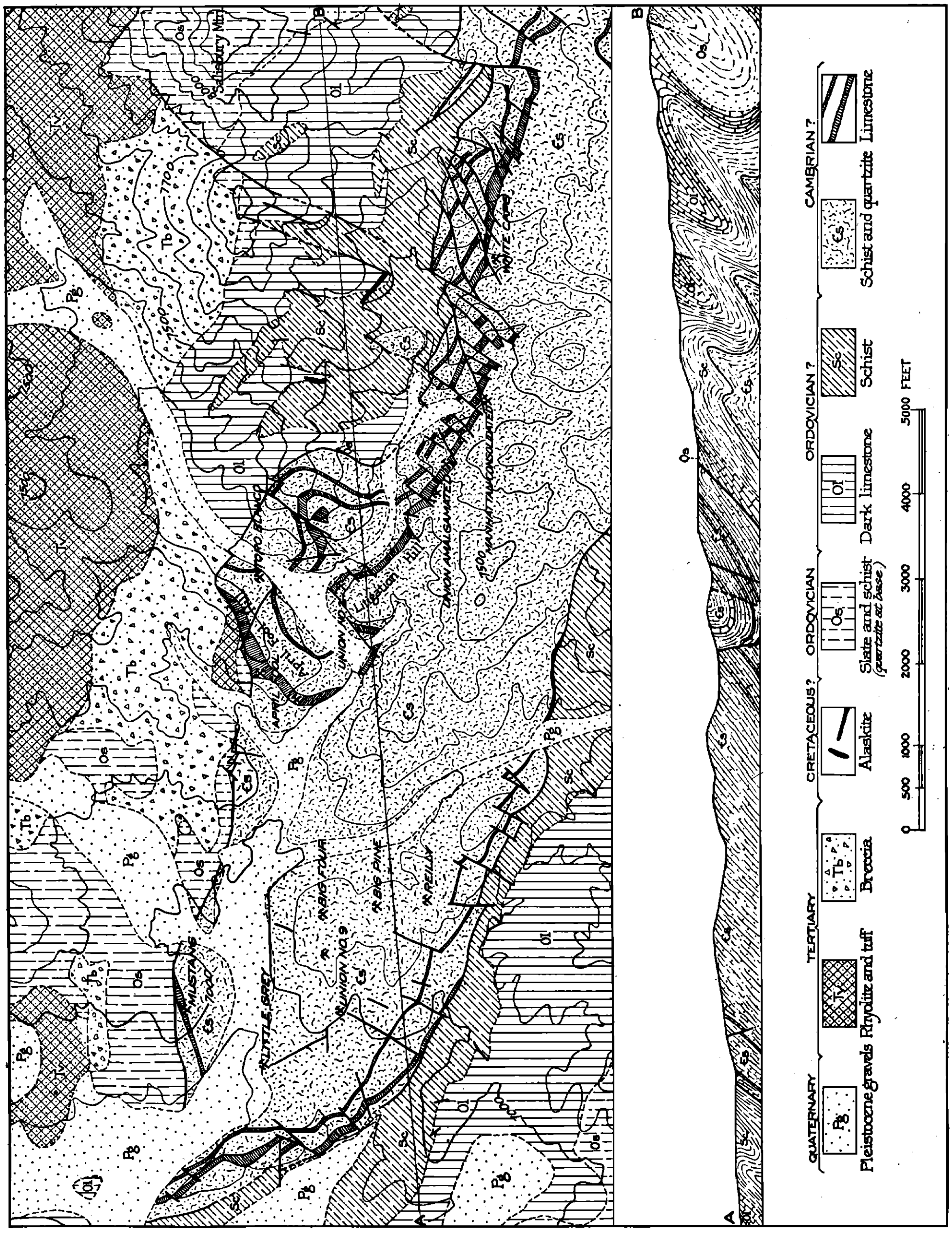


FIG. 2. Geologic map of the productive portion of the Manhattan district.

faults of considerable magnitude which in places cut the lavas but do not appear to extend to the sediments of the Manhattan district. These appear to be younger than the intrusion of the andesite prophyry and probably owe their origin to the readjustments following this intrusion. There is likewise evidence of a period of faulting in the lavas prior to the andesite intrusion.

Erosion.—The lava-covered region was eroded until an extremely mature topography, approaching the peneplain stage, was reached. The topography was fairly general over this portion of the Great Basin region, for Ball[6] mentions the existence of similar old topographic forms on other ranges to the south, and Meinzer[7] has found a similar mature topography on the Toyabe Range. Ball considers this mature land surface to be late Pliocene in age, as it is later than the "later rhyolite" of early Pliocene age and older than the later tuffs and older alluvium which mark the transition from Pliocene to Pleistocene. Hence the major portion at least of the mountain-building movements must have been confined to the early Pleistocene, for at the period marked by the Pleistocene lakes a topography approaching the present had been attained.

The eastern face of the Toyabe Range, a few miles west of Manhattan, presents a well-marked fault scarp. Faulting has continued until recent times, for Meinzer[8] reports that fault scarps cut the alluvial fans at the canyon mouths.

Small patches of Pleistocene gravel occur here and there along the borders of Manhattan Gulch, and the deep gravels of the gulch contain fragments of bones of Pleistocene mammals.

It is evident that a topography which at least in its main outlines resembled the present, has been developed in Pleistocene time. During a period of milder climate than the present, pre-

[6] Ball, S. H., "A Geologic Reconnaissance in Southwestern Nevada and Eastern California," U. S. Geol. Survey Bull. 308, pp. 16–17, 99, 119, 161, 202, 1907.

[7] Meinzer, O. E., "Ground Water in Big Smoky, Clayton and Alkali Valleys, Nev.," U. S. Geol. Survey Water Supply Paper 423, p. 21, 1917.

[8] Meinzer, O. E., *op. cit.*, p. 22.

sumably contemporaneous with the Pleistocene lakes Bonneville and Lahontan, two lakes existed in Big Smoky Valley.[9]

ORE DEPOSITS.

VEINS.

The ores of the Manhattan district occur in veins and as replacement deposits in limestone. Two types of vein deposits are present, an unimportant older group, connected in origin with the intrusive grandiorite masses of the region, and a younger group which is regarded as having been formed during the period of Tertiary volcanism, although the productive deposits are inclosed in the Cambrian sediments. The replacement deposits in the Cambrian limestones are allied mineralogically with the Tertiary veins, and, though the evidence is inconclusive, they are regarded as of contemporaneous origin.

Older Veins.—Veins of the older groups have not been profitably worked in the Manhattan District, though elsewhere in the region deposits genetically connected with the granodiorite and showing mineral associations characteristic of a more deep-seated origin than the Tertiary veins have supported workable silver mines, as at Belmont, 15 miles to the northwest of Manhattan, and Barcelona, near the crest of the range between Belmont and Round Mountain. In the Manhattan District the veins representing this epoch of mineralization are characteristically narrow and of no great continuity. They are composed of white glassy quartz with minor amounts of calcite and here and there contain patches of coarsely crystalline sulphides, including pyrite, galena, tetrahedrite, and chalcopyrite. The tenor in precious metals is low and the silver content is commonly greater than the gold. Tourmaline occurs as a minor gangue mineral in a few veins of this type. In one vein a little feldspar (orthoclase or albite) is present, thus forming a connecting link with the quartzose segregations of the aplite dikes.

Tertiary Veins.—The volcanic rocks, including the andesite

[9] Meinzer, O. E., *op. cit.*, p. 30.

porphyry, which is post-Siebert (Miocene) in age, contain small veins, apparently not continuous over long distances, which usually follow joint cracks or minor faults in the lava. The ore of these consists of minute veins of comby iron-stained quartz, with minor amounts of tabular calcite, which is largely replaced by quartz, and rarely fluorite and adularia. Pyrite has been present but is now completely oxidized to limonite. Here and there minute specks of free gold can be seen on the surface of the grains of oxidized pyrite.

The veins of Tertiary age in the Cambrian schists have been the largest producers of the Manhattan district. These are confined to the vicinity of Gold Hill, just west of the town. The ores are of relatively simple type. At the Reilly Fraction, Big Pine and Big Four mines the schists are traversed by innumerable little veinlets, for the most part following the bedding and jointing. These stringers contain free gold in a gangue consisting chiefly of comby quartz, but in places containing quartz pseudomorphic after tabular calcite together with clusters of adularia crystals. The enclosing schists are pyritized in places, but this pyrite is said to be practically barren. The zone of workable ore is fairly well defined and is about 50 feet wide and 800 feet long. In the Big Four mine the ore is stoped to a depth of 300 feet, about 100 feet above permanent water level, but most of the production from the three mines has come from less than 100 feet depth.

The group of mines west of the summit of Gold Hill, including the Stray Dog, Jumping Jack, Union No. 9, and Little Gray, shows the same type of mineralization, but here the veins are better defined and follow faults. There has been later movement along many of the veins and also along planes intersecting the veins at small angles. Where this has occurred, gold, probably of secondary derivation, is found in association with crushed vein material and gougy manganese oxide.

The mineralogical character of the schist ores, particularly the presence of abundant adularia and lamellar calcite replaced by quartz, indicates that they belong to the class of veins formed under near-surface conditions. The similarity of vein filling to that of the unproductive veins in the lavas suggests very strongly that both sets are of contemporary origin.

DEPOSITS IN LIMESTONE.

The ore deposits in the limestone beds of the Cambrian show most complex mineralization and a wide variety of minerals. Productive mineralization is almost entirely confined to a single limestone bed, the upper of the three lower limestones, locally known as the White Caps limestone. This bed has been traced from a point about a mile east of the White Caps mine through Litigation Hill to the summit of April Fool Hill, where it is cut off against the overthrust fault. Throughout its course it is broken by closely spaced normal faults, mostly of small throw. This faulting appears to be most intense and complicated in the region between the White Caps and Manhattan Consolidated shafts. A detailed study of this region was made by Messrs. McCraney and Dynan of the White Caps Company in connection with the White Caps-Morning Glory litigation in 1917, and through the courtesy of the officials of the White Caps Company, their map, with slight changes by the writer, is here reproduced (Fig. 3). The region west of the Consolidated shaft was mapped by the writer on a much smaller scale, which admits of showing only the more important of the faults.

Occasional reverse faults strike in the same general direction as the limestone and are shown by the repitition of the limestone on the 300-foot level of the Manhattan Consolidated, and on the 600-foot level of the Union Amalgamated.

The different mines in the limestone, although near neighbors, show such a wide diversity in their mineralization that a short description of each will be given before the theoretical side of the ore deposition is discussed.

White Caps Mine.—The White Caps mine appears to mark the eastern limit of profitable mineralization of the limestone. The Zanzibar, White Caps Extension and Red Caps prospects have explored the limestone bed to the east, but so far without success.

The White Caps mine is developed by seven levels, the lowest of which is 800 feet below the collar of the shaft. The limestone is here cut by three major faults which strike northeasterly and dip southeast. These are known as the East Fault, White Caps

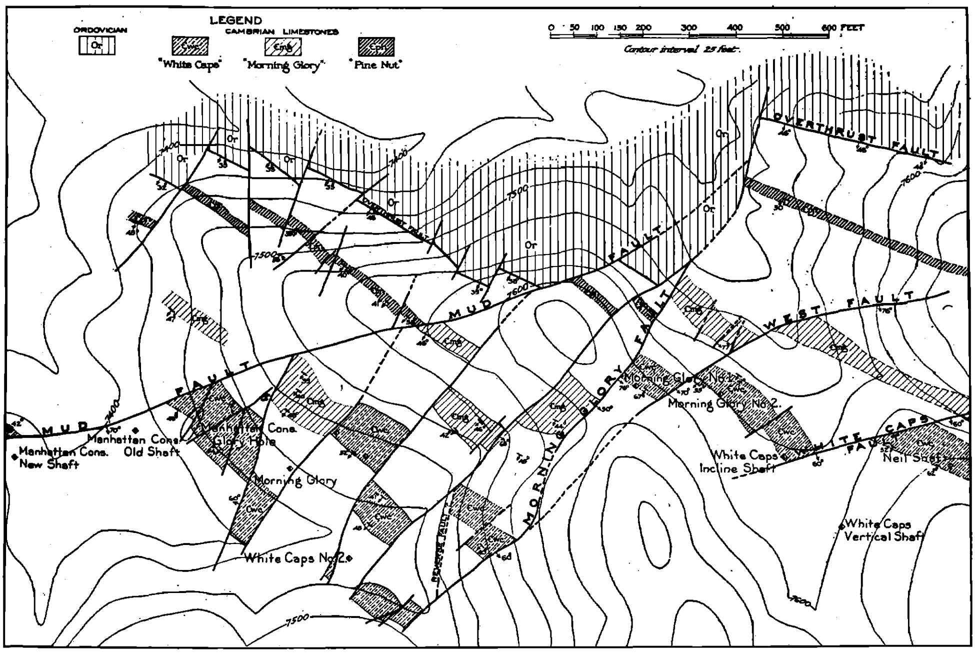


FIG. 3. Geologic map of area between the White Caps and Manhattan Consolidated mines, by O. McCraney and J. L. Dynan, with minor modifications by H. G. Ferguson.

Fault and West Fault. There are also a number of small northerly faults whose horizontal displacement in most cases does not exceed 5 or 10 feet. There has been more recent movement on the three main faults than on the minor faults, since they cut the earlier series and contain rounded fragments of ore. The earlier faults preceded the ore deposition and apparently to a large extent controlled it. They are cemented by ore and almost lose their identity in the ore bodies.

The ore bodies occur as large replacements in the limestone. It is rare that mineralization extends completely across the bed but usually follows one wall, more commonly the footwall. The areas in which the small faults are most numerous appear to be best mineralized. It is not uncommon for the ore and associated mineralized limestone to have a horizontal section of as much as 100 by 30 feet. Two main zones of mineralization have been developed, the east ore body which has yielded ore from the

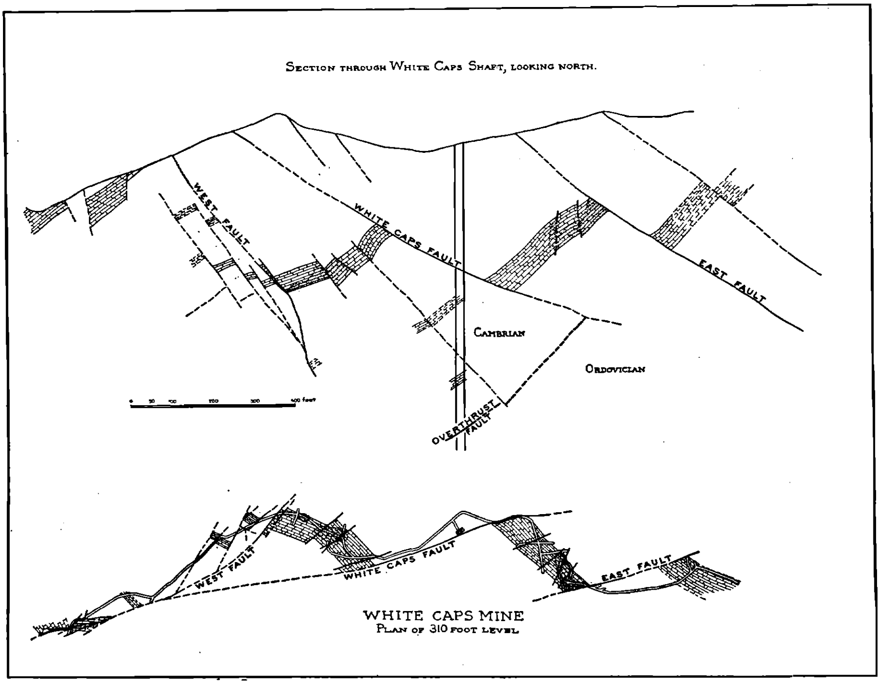


FIG. 4. Section through White Caps shaft, looking north; and plan of 310-foot level. (Mineralized areas shaded.)

surface to the 800-foot level, and the zone containing the West and Shaft ore bodies, which has been productive from near the 100-foot level to the 550-foot level. The eastern ore body has a steep easterly pitch, which brings it in contact with the east fault between the 550 and 800-foot levels. The western body is in contact with the White Caps fault between the 450 and 550-foot levels.

The gangue minerals of the White Caps mine are calcite, quartz, and less commonly dolomite, fluorite, and leverrierite. The metallic minerals include arsenopyrite, pyrite, stibnite, realgar and orpiment. Cinnabar is reported to have been present in the ore found above the 200-foot level.[11] The arsenopyrite, realgar, and orpiment are auriferous, but visible gold is completely lacking even in the oxidized ore. Oxidized minerals, present only in minor amount and confined to the two upper levels, include limonite melanterite and oxidation products of stibnite such as valentinite and stibioconite.

The following analysis of ore from the 300-foot level is quoted from Dynan's paper:[12]

SiO_2.	Al_2O_2.	CaO.	Fe	S.	Sb.	As.	Mgo.	H_2O.	CO_2.	Total.
55.8	1.8	7.2	8.9	8.2	0.7	1.5	3.2	0.8	9.2	97.3

Dynan has calculated from this the following mineral composition:

Pyrite	13.8%
Arsenopyrite	3.3
Stibnite	1.0
Calcite	19.6
Quartz	52.0
(Ca, Fe, Al) Silicates	7.4
	97.1

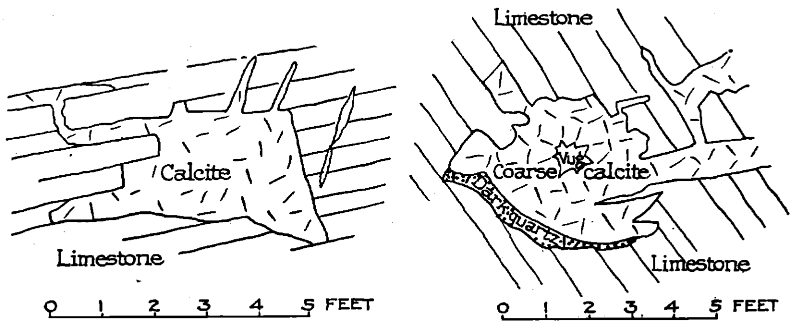
Ore from the lower levels of the eastern ore body shows a much higher percentage of arsenic.

The earliest of the minerals associated with the ore is white calcite. Huge rhombs are often observed in large irregular shrinkage cavities. The mineral is coarsely crystalline, and cleavage faces 8 inches across are frequently seen. The alteration of limestone to coarse calcite commonly follows the bedding and joint planes of the limestone. These replacements vary in

[11] Dynan, J. L., "The White Caps Mine, Manhattan, Nev.," *Mining and Scientific Press,* vol. 13, p. 885, Dec. 16. 1916.

[12] Dynan, J. L., *lac. cit.,* p. 884.

size from small lenses an inch or two across to large masses extending nearly across the limestone bed. The calcite is usually glaring white in color, except where the presence of finely divided realgar imparts a pinkish tinge. In a few places, however, small pieces have been obtained approximating Iceland spar in clearness and transparency. As far as known, the calcite itself is everywhere barren and is most plentiful near the outer edges of the ore bodies. In parts of the mine some coarse white



FIGS. 5 and 6. Calcite replacing limestone, 400 foot level, White Caps mine.

calcite occurs unaccompanied by ore, and is also found here and there throughout the district, even in the dark Ordovician limestone, though it is best developed in the ore-bearing limestone. The calcite is persistent in depth. The best ore of the mine consists of a dark, fine-grained quartz, in places so dense as to have the appearance of black jasper. This occurs as a replacement of the limestone and, to a less extent, of the coarse calcite. The quartz is closely confined to the ore bodies and does not show the wide distribution characteristic of the barren calcite. The replacement of limestone by quartz has involved a considerable loss of volume, indicated by numerous drusy cavities, usually elongate with the bedding of the limestone. In these minerals of later age—dolomite, stibnite, realgar, and orpiment, have been deposited. In places this reduction of volume, possibly assisted by the abstraction of the arsenopyrite by later solutions, has been sufficient to permit collapse and local brecciation of the quartz, following later movement along the major faults.

The hand lens discloses occasional minute specks of pyrite in the quartz. Under the high power of the microscope, however, the dark color is seen to be due to the presence of carbonaceous matter and minute crystals of a gray metallic mineral. These range from the lower limit of visibility to a maximum of 0.05 mm., but most of them are less than 0.22 mm. in diameter. Many of these little crystals are so twinned as to resemble minute jackstones. Qualitative tests indicate that the metallic mineral is arsenopyrite. Evidently it is highly auriferous for assays exceeding $200 per ton have been obtained from this type of ore. No gold can be seen under the microscope and none is obtainable by amalgamation. Palmer,[13] however, found that this dark ore, concentrated by panning and treated with nitric acid, yielded minute specks of free gold.

A little muscovite was observed in some of the thin sections of the dark quartz. It is not certain whether this is contemporaneous with the inclosing quartz or is residual from the limestone, though no muscovite was found in the few sections of the limestone examined.

The replacement ore deposits are later than the first period of faulting, since both quartz and calcite, but especially the quartz, are found recementing the shattered zones where the minor faults enter the limestone. On the other hand, they are clearly older than the last movement on the larger faults for these contain rounded fragments of the quartz.

Dolomite, stibnite, realgar and orpiment, with minor leverrierite and rarely fluorite, are clearly younger than the quartz and calcite since they were deposited in open spaces of the cellular and brecciated quartz. The realgar and orpiment, at least, are subsequent to the second period of faulting since small crystals occur in the fault gouge.

Stibnite is found throughout the deposit, but is more prominent in the western part of the mine. Small crystals are frequently found in the vugs of the dark quartz. Its most usual occurrence

[13] Palmer, W. S., "Occurrence of Gold in Sulphide Ore," *Eng. Min. Jour.*, vol. 107, pp. 923–924, May 24, 1919.

is in roughly radiate crystalline masses, in places several inches in diameter, which replace the limestone or coarse calcite, or more rarely the dark quartz. In places small "sunbursts" of stibnite crystals occur along cleavage planes of the coarse calcite and small needles were found in the fault gouge of the later faults. In all these positions, particularly in the eastern ore body, stibnite may be closely intergrown with realgar. A rare occurrence of stibnite is in the form of delicate hair-like crystals found in cavities in the calcite and rarely in the quartz. Orpiment is found in this same habit and association, but not realgar. Although the stibnite is practically barren of gold it is confined to the ore bodies. Only rarely do small clusters of stibnite crystals occur ouside of the mineralized areas.

Realgar occurs in large amounts in the eastern ore body but only sparingly in the western part of the mine. In the stope above the 665-foot level and on the 400-foot level realgar was present in such large masses that it was smelted as an ore of arsenic. The mode of occurrence is very similar to that of the stibnite. It is found as a replacement of the coarse calcite, in crystalline masses whose boundaries follow the cleavage planes of the calcite, in narrow streaks following the cleavages; it is also common as a filling of the numerous cavities in the dark quartz. A stope above the 665-foot level shows realgar and dark quartz in irregular bands up to several inches across. In places blocks of practically pure realgar a couple of feet in diameter have been obtained. The realgar is gold-bearing, though, as far as the writer is aware, does not yield such high assays as are sometimes obtained from the dark quartz. Smelter shipments of 30 per cent. arsenic, carried $20 to the ton in gold.

In the vicinity of the ore, but outside the ore bodies, realgar is more widely distributed than the other minerals. It is the only ore mineral found outside the limestone and occurs in the foot and hanging wall slates in small veinlets and impregnations for distances of a few feet from the limestone. Realgar, in small scattered crystals, is found in places in the fault gouge of the faults of the most recent series, particularly the White Caps fault. In general realgar shows the same associations and mode of occurrence as the stibnite, and the two minerals are often found closely intergrown. In one specimen realgar was found in a cluster of little radiating rods, as if replacing stibnite.

Realgar occurs in quantity throughout the eastern ore body from the 300-foot level to the 665-foot level. Above and below this it is present only in minor amount.

Orpiment also occurs in the eastern ore body but only above the 400-foot level. It is clearly an alteration product of the realgar. All stages of the alteration process can be observed, beginning with threads of the orpiment in the realgar, through specimens showing cores of realgar surrounded by orpiment to pure orpiment. Only very rarely does orpiment occur, which is not clearly the result of alteration of realgar in place. In a few of the vugs in the coarse calcite there are delicate clusters of hair-like orpiment crystals.

The change from realgar to orpiment did not free any of the gold contained in the realgar. The orpiment is said to have about the same tenor as the realgar.

Later pyrite is found, particularly in the upper levels. This, like the stibnite and realgar, occurs in drusy open spaces in the dark quartz or more rarely along the cleavage faces of the white calcite. It is inconspicuous in amount compared to the stibnite and realgar. Marcasite has been reported, but its presence could not be definitely proved.

Among the later minerals of the deposits are minor amounts of quartz and calcite of a second generation, and rarely leverrierite. Small crystals of fluorite on projecting quartz crystals of one of the druses in the fine-grained quartz were observed on the 200-foot level.

Oxide minerals are nearly absent even in the upper levels. In the lower levels the waters flowing from the mineralized limestone are depositing stalactites and sludgy masses of limonite which contains arsenic, but whether as an arsenate or oxide is not known. In some of the stibnite specimens collected from the 100 and 200-foot levels there is a partial alteration to valentinite and stibiconite. Microscopic crystals of a transparent mineral with high refractive index which may be arsenolite were observed in places, and pharmacolite is probably also present in small amount.

No free gold has been found in the White Caps mine. The bullion obtained from the cyanide process contains almost no silver, having a value of over $20 an ounce. The ratio of gold to silver is said to be about 17 to 1. The gold is clearly associated with the arsenical minerals, particularly the arsenopyrite. Possibly this explains its abnormal purity since arsenopyrite, realgar, and orpiment all tend to precipitate gold rather than silver from solutions.

Manhattan Consolidated.—The Manhattan Consolidated has been developed by five levels to a depth of 500 feet. The 100-foot and 500-foot levels were not accessible at the time of the writer's visit. The shaft cuts the overthrust fault below the 400-foot level. A normal fault of large throw, known as the Mud Fault, cuts the workings in a northeasterly direction and dips to the southeast.

The limestone bed is repeated on the 300-foot level, possibly by a reverse fault nearly parallel to the strike, and small faults of nearly northerly strike and small displacement are frequent. These are older than the faults of the northeast series, such as the Mud Fault. Motion parallel to the bedding is shown in gouge streaks along the top of the limestone.

The ore west of the fault is similar to that of the eastern part of the White Caps mine. The ore body is formed by the replacement of limestone on both sides of a small northerly fault. Coarse white calcite is prominent, particularly near the edges of the mineralized area. The best ore is a dark quartz much like that of the White Caps but containing only a little microscopic arsenopyrite and more pyrite. Stibnite is present in small amount, in drusy cavities in the dark quartz and in the limestone and calcite. Realgar is occasionally found. Small realgar crystals occur in the gouge along the Mud Fault, particularly near the surface.

The ore differs from that of the White Caps mine in that there is a considerable proportion of silver associated with the gold. Bullion from the eastern ore body is said to have a fineness of about 620.

The ore west of the Mud Fault differs markedly from that of the east ore body. Instead of a large replacement body, mineralization is closely associated with small fault fissures, giving the so-called "vein deposits." Four of these have been exploited; two follow northeasterly faults of small throw; another, less well defined, a fault nearly parallel to the strike of the limestone; and the fourth rather irregular mineralization along the top of the limestone. The mineralization does not extend for more than a few feet from the controlling fissure, and the ore shoots are small and irregular. Both coarse calcite and fine-grained quartz are present. These occur as replacements along the bedding of the limestone, thinning out away from the fissure. The quartz resembles that of the White Caps in texture, but is lighter in color, bluish gray rather than black. Pyrite is present, but arsenopyrite is lacking.

Irregular solution channels, in places following the dip of the limestone for 300 feet or more, are common in the limestone near the fissures. These contain deposits of muddy material, apparently chiefly limonite and manganese oxide, in which wire gold occurs.

Fluorite is plentiful in the ore west of the fault, in the larger cavities in the fine-grained quartz. Stibnite and realgar are absent in the western part of the mine.

Other Mines.—The same limestone bed outcrops to the westward from the Manhattan Consolidated along the crest and north side of Litigation Hill. The principal development has been done from the Bath and Earle shafts, and the Union No. 4 (Kane shaft). The deepest of these is the Earle shaft, which has followed the dip of the limestone for a distance of 700 feet. The mineralization is similar to that of the western part of the Manhattan Consolidated and is dependent upon the same types of small northerly faults. The northeasterly faults of larger throw seem to be later than the period of mineralization marked by the coarse calcite and fine-grained quartz. The ore shoots are small and irregular, and it is said that no important bodies of workable ore were found at a depth greater than 300 feet on the incline.

Coarsely crystalline white calcite, fine-grained bluish quartz, and fluorite, and a little leverrierite, are the principal gangue minerals. The fluorite and leverrierite occur in cavities of the quartz. The quartz carries more or less pyrite, in grains barely visible to the naked eye, but apparently no arsenopyrite. Microscopic study revealed rare grains of adularia. The gold is contained in the fine-grained quartz, presumably in the pyrite, and also occurs as minute specks of free gold in the oxidized ore.

The same limestone follows the crest of April Fool hill until it is cut off by the overthrust fault. The limestone is extensively mineralized and has been mined for nearly the whole length of the outcrop. The high-grade ore, which gave the hill its fame in the early days of the camp, was apparently a near-surface phenomenon; most of the ore appears to have been taken out at depths of less than 30 feet, and no stoping extended below 100 feet.

The ore occurs along small faults which offset the limestone a few feet. Coarse calcite and fine-grained quartz appear as replacements of the limestone following the bedding plans irregularly for short distances from the fissures. The valuable ore, however, seems to be contained in small veinlets following these fissures. These consist chiefly of quartz and fluorite with a little calcite. The quartz carries free gold in places, and minute pyrite grains. Most of the coarse gold was found along the walls of the veinlets between the calcite and the wall rock. In places small rhombic crystals of adularia occur with the quartz.

On the northern side of the hill the limestone has been developed by several tunnels, the lowest being about 140 feet below the highest point of the outcrop. Here the ore is of different character. The rich ore of the surface workings is lacking, and that extracted has seldom yielded over $20 per ton. The mineralization takes the form of an irregular replacement of limestone extending outward from small fissures. For the most part the ore is similar to that of the mines on Litigation Hill, except for a higher proportion of fluorite. In places, particularly in the lowest tunnel, there are large, irregular caverns in the limestone, which may be lined with large fluorite crystals. Commonly, however, the roof and walls show large numbers of white inverted domes, up to about 6 inches in diameter. These consist of alternate layers of fine-grained white quartz and white clayey material of sericitic appearance, the optical properties of which correspond to leverrierite, a hydrous aluminum silicate. The leverrierite layers are rarely pure and commonly contain large numbers of little grains of quartz and chalcedony scattered through them. More rarely crystals of fluorite are inclosed in the leverrierite. A few pseudomorphs of limonite after pyrite also occur in the leverrierite. This material carries a small amount of gold, said to be about $4 per ton.

Upper Limestone Ores.—The upper limestone beds, near the top of the Cambrian, have been prospected extensively but contain ore only on the Mustang claim close to the overthrust fault. The limestone here shows the effects of contact metamorphism and is largely altered to diopside. Gold has been obtained close to the surface from little fissures, similar to the veinlets which yielded the rich surface ore on April Fool Hill, and small replacement veinlets carrying quartz and fluorite. Small flakes of barite were also found in the concentrates from this ore. Most of the production, however, has come from peculiar pipe-like ore shoots which follow the dip of the limestone, usually along the intersection of a bedding plane with a well-developed joint plane or small fault. These pipes are nearly circular in cross section and from 8 inches to 2 feet in diameter. Around each is a rim of fine-grained white quartz, a couple of inches thick. The interior of the pipes is composed of a soft white material, with the same silky luster characteristic of sericite. The optical properties, however, were found to agree more nearly with the mineral leverrierite, a hydrous aluminum silicate, with the formala $Al_2O_3.2SiO_2.2\frac{1}{2}H_2O$.[14] The following partial analysis, made by R. K. Bailey, of the U. S. Geological Survey, confirmed this determination.

	Per Cent.
H_2O — 100	4.56
H_2O + 100	16.15
K_2O	0.31

Small grains of quartz occur intimately mixed with the leverrierite, and it was found impossible to separate sufficiently pure material to warrant a complete analysis. Specks of limonite scattered irregularly through the pipe represent original pyrite. Free gold occurs throughout the leverrierite, in sufficient amount to have yielded over $40,000 in a distance of about 100 feet along the pipe. The gold is mostly very fine, but occasionally occurs as round pellets which look like small shot. As far as could be determined from microscopic examination, the gold is in all cases surrounded by the leverrierite and has apparently no close association either with the oxidized pyrite or disseminated quartz.

The principal pipe has been followed down the dip of the limestone for about 100 feet. Several smaller pipes branching upwards from the main pipe were encountered but not developed. The richest spots were said to have been at the intersections of the main pipe with its branches. The lower workings were not accessible at the time of the writer's visit, but it is said that at depth the pipes became less well defined and difficult to follow.

MINERALOGY.

Distribution and Paragenesis.—The following table illustrates the principal variations of the perplexing variety of limestone ores encountered as one crossses the district from east to west, along a distance of about 2 miles. For comparison the ores of the schists have also been included:

[14] Larsen, E. S., and Wherry, E. T., "Leverrierite from Colorado," *Jour. Wash. Acad. Sci.*, vol. 7, pp. 208–217, 1917.

TABLE SHOWING PRINCIPAL MINERALS PRESENT IN THE LIMESTONE ORES.
Bold face and parentheses indicate relative importance or scarcity, respectively.

	Native Gold.	Arsenopyrite.	Pyrite.	Stibnite.	Realgar.	Orpiment.	Fluorite.	Quartz.	Calcite.	Leverrierite.	Adularia.	Barite.
White Caps, Eastern part		X	(X)	(X)	**X**	X		**X**	**X**			
White Caps, Western part		X	(X)	**X**	(X)		(X)	**X**	**X**	(X)		
Manhattan Con., Eastern part		(X)	X	X	(X)		X	**X**	X	(X)		
Manhattan Con., Western part	X		X				**X**	**X**	X	X		
Litigation Hill	X		X				**X**	X	X	X	(X)	
April Fool Hill	X		X				**X**	X	X	**X**	X	
Mustang	X		(X)				X	X	(X)	**X**	X	(X)
Sunset prospect			X	**X**				X	(X)			X
Schist ores	X		X					**X**	(X)		**X**	

The paragenesis of the principal minerals of the limestone mines appears to be as follows: (1) Coarsely crystalline white calcite, (2) fine-grained quartz containing, in the White Caps mine, contemporaneous arsenopyrite and elsewhere pyrite. In some deposits a little adularia appears to have crystallized contemporaneously with the quartz. (3) Fluorite and leverrierite and rare adularia, found chiefly in the eastern deposits. In places quartz and leverrierite are closely intergrown. (4) Stibnite and realgar are of distinctly later date, together with later pyrite, quartz and calcite. All the ores of the first group though later than the first period of faulting, and are older than the most recent movement along the major faults. The realgar and possibly the stibnite on the other hand were introduced subsequently to the second period of faulting. It appears therefore that in the White Caps and the eastern part of the Manhattan Consolidated mines, at least, there is a superposition of two or more periods of mineralization of widely separated ages.

The ores show great variance in character along the same bed of limestone. Leverrierite is prominent on April Fool Hill and in the higher limestone on Mustang Hill, and is nearly lacking at the eastern end of Litigation Hill; fluorite also decreases to the eastward, though it is found in the Manhattan Consolidated, and very rarely in the White Caps. The fine-grained quartz, on the other hand, is more prominent in the eastern mines. Arsenopyrite is largely confined to the White Caps, though it may be present in small amount in the dark quartz of the Manhattan Consolidated. Pyrite is persistent throughout, but is less prominent in the White Caps than the other mines. The coarse calcite occurs throughout and indeed is not confined to the vicinity of the ores, but seems to occur sporadically in all the limestones, particularly where fissured.

The difference in the ores along so short a distance is probably due in large measure to changing character of the solutions along the strike. It may be also to some extent, due to differences in original vertical position. The larger faults have their downthrow sides to the eastward, hence at the time of the deposition of the first series of minerals the White Caps stood highest, followed by the eastern part of the Consolidated and the Litigation Hill mines, and lastly April Fool Hill, which was much lower than the White Caps at the time of the ore deposition, though there is no way of determining how much of the displacement is due to post-mineral faulting.

The stibnite of the limestone mines is believed to be of later date. That stibnite should be confined to the limestone and nowhere present in the neighboring schist is probably due to the influence of the country rock, since the waters passing through the limestone would contain bicarbonate, which would precipitate stibnite from an alkaline solution.

Realgar: Occurrence and Origin.—Realgar is found in notable amount only in the White Caps mine, where it occurs in the same general manner as stibnite. It is, however, rather more migratory in its distribution, since it is found in the schist at some distance from the limestone, and small crystals of realgar have formed in the gouge accompanying the later series of faults, whereas stibnite is rarely found in these positions. Realgar and stibnite are in places found closely intergrown, and it is believed that they are approximately contemporaneous, although in one specimen realgar appears to have replaced stibnite. Realgar is found only where the dark quartz carries arsenopyrite and not in those mines in which pyrite is the principal metallic mineral. It occurs in quantity in the White Caps mine, only down as far as the 665-foot level. Below this the ore consists of very cavernous dark quartz, brecciated and crumbly in places, with occasional patches and scattered crystals of realgar. Dynan[15] has suggested that the realgar is a secondary mineral derived from the arsenopyrite. The fact that realgar is confined to the White Caps mine, which is the only mine in which arsenopyrite is present in notable amount, renders this supposition extremely probable. Normally, under the action of oxidizing waters, scorodite or pharmacosiderite should be the end point of oxidation of arsenopyrite.[16] There appear to be numerous instances, however, in which realgar is a secondary sulphide,[17] and Lindgren[18] even says:

"Realgar and orpiment are probably always supergene sulphides but they are not found in the secondary zones of copper deposits. They are rather more characteristic of the oxidized zone, and often are derived from arsenopyrite. The chemistry of their deposition is uncertain."

It is possible that the method of formation of supergene realgar from arsenopyrite is analagous to the formation of sulphur in the first stages of the oxidation of pyrite. Stokes[19] gives the following equation:

$$FeS_2 + Fe_2(SO_4)_3 = 3FeSO_4 + 2S.$$

The equivalent reaction in the case of arsenopyrite would be:

$$FeAsS + Fe_2(SO_4)_3 = 3FeSO_4 + AsS.$$

Stokes, however, did not obtain arsenic sulphide when arsenopyrite was treated with ferric solutions.[20]

15 Dynan, *op. cit.*, p. 885.

16 Lindgren, W., "Mineral Deposits," p. 898, New York, 1919.

17 Emmons, W. H., "The Enrichment of Ore Deposits," Bull. U. S. G. S. No. 625, p. 466, 1917.

18 *Loc. cit.*, p. 899.

19 Stokes, H. N., "On Pyrite and Marcasite," U. S. Geol. Survey Bull. 186, p. 15, 1901.

20 *Loc. cit.*, p. 33.

In this case, moreover, the realgar is not confined to the zone in which oxides occur but is found to the lowest depth yet explored, though only prominent above the 665-foot level.

The similar mode of occurrence of the realgar and stibnite suggests another possible explanation. If, as appears to be the case, the stibnite is distinctly later than the quartz and arsenopyrite it is possible that the hypogene solutions, presumably deficient in oxygen, which deposited the stibnite also attacked the arsenopyrite. The arsenic thus dissolved would be deposited as realgar in the zone where the ascending waters began to be contaminated with the bicarbonate of the supergene waters of the limestone.

The fact that sibnite is barren and the realgar gold bearing is perhaps additional evidence of the secondary origin of the realgar. For if the realgar were derived from the arsenopyrite the gold present in the arsenopyrite would tend to migrate with the arsenic to the realgar, while if both stibnite and realgar were of hypogene origin and contemporaneous, it would not be expected that the gold would be present in only one of the two minerals.

On the other hand realgar has often been found in hot spring deposits, and there is no inherent reason why it should not be found as a primary mineral in ore deposits formed at shallow depth. In the microscopic examination of the White Caps ore, the writer has not been able to find any clear evidence of alteration in place of arsenopyrite to realgar. The large amount of realgar found between the 400 and 660-foot levels would require the alteration of an enormous amount of arsenopyrite, and there is no evidence of any marked leaching of the arsenopyrite in the upper levels. There is a small amount of later pyrite, apparently contemporaneous with the realgar and stibnite but not at all comparable in volume to the realgar. It may be, however, that an iron-rich gossan has been eroded.

Oxidized Minerals.—The amount of oxidation, particularly in the deposits in the limestone, is comparatively small. In the White Caps and Manhattan Consolidated mines slightly oxidized stibnite occurs in the surface workings. The oxidized antimony minerals are inconspicuous and cannot everywhere be certainly identified. The principal ones appear to be valentinite and stibiconite. The latter appears to have formed both directly from the stibnite and as an alteration product of the valentinite. Palmer[21] records the presence of kermesite as well. Except for rare minute grains of what may be arsenolite in ore from the upper levels of the White Caps and the presence of arsenic in the limonitic material deposited on the walls of the drifts, no oxidized arsenical mineral has been recognized. In the pyrite-bearing ores of the schists, on the other hand, the pyrite has in places been altered to limonite to depths of 300 feet or more.

Orpiment: Occurrence and Origin.—Orpiment, which is found in the upper 400 feet of the eastern ore body of the White Caps, is clearly derived from realgar, presumably by the action of oxidizing waters. Specimens can be collected which show all stages of alteration, from the first development of threads of orpiment along little cracks in the realgar through cores of realgar, surrounded by orpiment, to pure orpiment. It is difficult to understand why the change from realgar should be to a mineral with higher sulphur content (AsS to As_2S_3), without the formation of oxidized arsenical minerals at the same time. In the lower levels of the mine, however, below the zone in which the orpiment occurs, the mine waters flowing from fissures near the ore are deposting a limonitic sludge on the walls of the drifts. Qualitative tests show the presence of considerable arsenic in this material. Apparently orpiment is the stable sulphide under surface conditions, and the alteration takes place through oxidation of a part of the arsenic of the realgar rather than of the sulphur. This is soon redeposited in association with iron oxide; whether as oxide or an iron arsenate has not yet been determined. An analogous reaction is that by which chalcocite changes by oxidation to covellite.[22]

The alteration of the realgar to orpiment takes place with

[21] Palmer, W. S., "Formation of Quicklime in Roasting Ores from Manhattan, Nev.," *Mining and Engineering Journal,* vol. 104, p. 525, Sept. 22, 1917.

[22] Lindgren, W., *op. cit.,* p. 859.

comparative rapidity in the sunlight. Fragments of realgar left on the mine dump soon lose their bright red color due to the formation of a thin coating of orpiment. A small amount of pure realgar was placed under glass in the sunlight. Incipient alteration was noticed within a few days and in a few weeks the transformation to orpiment was well advanced. No recognizable arsenic oxides were found, though according to Dana[23] realgar alters in the light to orpiment and arsenolite.

To test the probability of the alteration of realgar to orpiment by oxidizing waters small amounts of realgar were placed in a dilute solution of ferric sulphate and gently heated. The realgar was in part altered to orpiment and arsenic oxide.

The hair-like crystals of stibnite and orpiment, which are sometimes found, suggest supergene sulphide deposition. C. Doelter[24] states that stibnite at 80° is slightly soluble in water and that recrystallization is also perceptible.

Gold.—At least a part of the gold in the rich surface ores is due to secondary deposition. No free gold has been found in the White Caps or eastern ore body of the Manhattan Consolidated. In the White Caps, and probably to some extent in the Consolidated also, the gold is present in the minute arsenopyrite crystals scattered through the dark quartz. The stibnite is barren, but the realgar and orpiment are both gold bearing, so it is apparent that in whatever form the gold is present in the arsenopyrite, it has remained with the arsenic through the succcessive changes from arsenopyrite to realgar and thence to orpiment. In the western part of the Manhattan Consolidated and in the Litigation Hill mines, free gold occurs as small flakes in sandy material consisting of minute fragments of quartz and calcite with manganese and iron oxides in irregular solution channels in the limestone. This was probably derived from the pyrite of the massive quartz and deposited by supergene waters. The rich

[23] Dana, E. S., "System of Mineralogy," p. 34, 1895.

[24] *Min. pet. Mitt.*, vol. 11, 1890, p. 322, cited by F. W. Clarke, "Data of Geochemistry," U. S. Geol. Survey Bull. No. 616, p. 689, 1916.

surface ores of the workings on April Fool Hill, in which the gold occurs in close association with calcite, are apparently due to secondary enrichment. These were very rich close to the surface, but nearly barren at shallow depth. Gold carried in acid surface waters would be quickly deposited in contact with calcite and superficial enrichment could not extend to any appreciable depth.

Secondary enrichment appears to have played a much more important part in the ores of the schists than in those of the limestones. In these deposits the richest ore is commonly found at the intersection of the principal vein with small fissures rich in manganese oxide. Since calcite is lacking in these deposits the lower limit of enrichment is at a greater depth than in the ores of the limestone, but rich ore does not seem to have been mined below about 200 feet. In the schist mines such as the Big Pine, where the gold occurs in a multitude of small stringers in the schist, there is little manganese oxide and no clear evidence of secondary enrichment.

RELATION OF ORE DEPOSITION TO FAULTING.

The productive mines of the district all lie in a belt extending about 10,000 feet from east to west and less than 2,000 feet from north to south. The overthrust fault marks the northern limit of productive mineralization. This fault is older than the numerous normal faults which cut the ore-bearing limestones and is undoubtedly contemporaneous with the intense folding which preceded the intrusion of the granodiorite.

Movement on the normal faults may have begun at the time of the granodiorite intrusion for an alaskite dike seems to follow one of the faults. The major normal faulting, however, probably did not take place until late Tertiary time, subsequent to the intrusion of the andesite porphyry.

Productive ore deposits occur only close to the overthrust fault, and along the southern or hanging wall side. Although the actual fault plane is nowhere mineralized, it is believed that the presence of this major fault was the determining factor in the localization of the deposits. The mines are all on the hanging-wall side of the overthrust and for the most part associated with the small normal faults of later date. It may be that the overthrust fault with its narrow zone of comparatively impervious gouge acted as a dam to prevent important migration of the solutions north of the fault, and that the intersection of the overthrust with the minor normal faults determined the principal channels followed by the ascending solutions. This furnishes a possible explanation for the localization of mineralization in the White Caps limestone, to the exclusion of the two similar beds at slightly lower horizons. The limestones at the White Caps mine and on Litigation Hill, while approximately parallel with the overthrust in strike, have a slightly steeper dip. Thus the White Caps limestone would be cut by the fault plane at a lower level than the two lower beds and uprising solutions controlled to the north by the overthrust would tend to be diverted along the first soluble bed.

AGE OF THE ORES.

Ores of deep origin and those characterized by minerals indicative of deposition at shallow depth are both represented in the Manhattan district. The former are represented by the small glassy quartz veins found here and there throughout the district. These veins seem to be clearly associated with the granodiorite intrusion, probably most closely with the final phase which produced the aplite dikes. Productive deposits of the same epoch have been mined within a few miles of Manhattan.

The small veins of the lavas and the veins in the schists of Gold Hill, on the other hand, show certain characteristics of veins formed at shallow depths, such as adularia and quartz pseudomorphic after lamellar calcite. Since ores of this type occur in the post-Siebert andesite, these veins can be assigned to a period between the late Miocene and the formation of the late Pliocene erosion surface. Presumably this period of ore deposition is genetically connected with the andesite intrusion.

The ores of the limestone are more complex and lack minerals or mineral associations clearly diagnostic of either of the above groups, and it is likely that more than one period of mineralization is represented.

Dynan[25] considers that the ore of the White Caps mine owes its origin to solutions emanating from the intrusive granite.

Outcrops of granitic rocks occur much nearer the mines than do the Tertiary igneous rocks. On the hill north of Litigation Hill there are two small dikes of a coarse-grained alaskite, and several small aplite dikes cut the sediments a short distance to the south. Two small masses of a much sericitized igneous rock, probably an aplite, have been encountered in the lowest level of the White Caps.

The coarse calcite, usually associated with some valuable mineralization, occurs in places close to the granodiorite and Dynan mentions[26] specimens of coarse calcite and garnet from the granodiorite contact which assayed 0.03 oz. gold per ton. Similar coarse calcite in the silver-lead deposits of the Darwin district, California, has been described by Knopf.[27] There it seems to be directly connected with an intrusion of granodiorite. On the other hand, this type of calcite is not present in limestones of the Belmont and Barcelona districts where the occurrence of the ore is clearly related to the presence of the granodiorite.

Leverierrite is present in all of the ore deposits in the limestone. This mineral is uncommon in ore deposits but was found by Larsen and Wherry[28] in quartz veins with manganese oxide. Racewinite from the Highland Boy mine of Bingham, Utah, described by A. N. Winchell[29] appears to be identical with leverrierite.[30] Here it occurs in ores associated with a monzonite porphyry intrusion.

[25] *Loc. cit.*, p. 885.

[26] *Idem*, p. 885.

[27] Knopf, A., "The Darwin Silver-Lead Mining District, California," Bull. 580, U. S. Geol. Survey, p. 7, 1915.

[28] Larsen, E. S., and Wherry, E. T., *loc. cit.*, p. 217.

[29] Winchell, A. N., "Racewinite, A Peculiar Mineral from Ore Deposits in Utah," Econ. Geol., vol. 13, pp. 611–615, 1918.

[30] Butler, B. S., "Ore Deposits of Utah," Prof. Paper No. 111, U. S. Geol. Survey, p. 113, 1920.

It is believed, however, that the weight of the evidence favors the probability that these ore deposits were formed fairly close to the surface and are of Tertiary age. The deposits are absolutely unlike those of Belmont and Barcelona, in which the primary ore consists of sulphides such as galena, sphalerite, tetrahedrite, and chalcopyrite in a quartz-calcite gangue, nor is there any similarity between these and the small unproductive veins of deep-seated origin found here and there throughout the Manhattan district. The large amount of fluorite likewise is considered indicative of deposits of the shallow rather than of the deep vein zone. Moreover, the presence of a little adularia intergrown with the fine-grained quartz is believed to form a connecting link with the quartz adularia veinlets of Gold Hill which clearly belong to the class of veins formed at shallow depth. Also the fine-grained drusy quartz suggests deposition nearer the surface than the coarsely crystalline quartz and sulphides of the ores of Belmont.

The principal minerals of the limestone deposits, quartz, fluorite, leverrierite, arsenopyrite, appear to have been deposited prior to the most recent movement along the larger faults. The stibnite and realgar, on the other hand, are younger than the latest faulting and appear to represent a still later period of Tertiary ore deposition. It is probable that there were two periods of late Tertiary mineralization, probably both subsequent to the intrusion of the andesite porphyry. It is possible, however, that the coarsely crystalline calcite may be a representative of the mineralization following the granodiorite intrusion.

CONCLUSIONS.

The productive mines of the Manhattan District occur close to large overthrust fault and are all in the upper or overthrust block. Although no ore deposition occurred in the fault plane itself, the presence of this fault is believed to have been the controlling factor in localizing ore deposition. Particularly favorable situations appear to be in localities where late normal faults displace the overthrust. Two series of normal faults are recognized, the first, characterized by small throw, steep dip, and general direction about north-northeast, and the other with generally larger throw, flatter dip and less accordant strike. While the two series may be of contemporaneous origin, there has been more recent movement along the faults of the second group. The faults of the first group may have been initiated by the intrusion of the granodiorite batholith, but the more important faulting is tentatively correlated with the intrusion of a mass of andesite porphyry of late Miocene or Pliocene age.

The ore deposits show a wide variety. Small quartz veins in the schists, with pyrite, chalcopyrite, tetrahedrite, and galena, have not proved workable. These are clearly of deep-seated origin and may be correlated with the granodiorite intrusion and are presumably late Cretaceous or early Eocene in age. The ores of the Cambrian schists show a mineral association characteristic of shallow zone deposition and may be genetically connected with the andesite porphyry. The characteristic minerals of these ores are quartz, in small comby veinlets, and pseudomorphic after tabular calcite, adularia, pyrite and free gold.

A bed of crystalline limestone occurring in the lower part of the Cambrian is heavily mineralized and shows a complex association of minerals. At the eastern part of the district the principal gangue minerals are coarse calcite and fine-grained quartz, and the metallic minerals arsenopyrite, pyrite, stibnite, realgar and orpiment. The ore occurs in large replacement deposits in the limestone closely connected with the faults in the earlier series. Stibnite, realgar, and orpiment, however, are later than the second series of faults. It is believed that the deposition of stibnite was due to a later period of ore deposition, and that the realgar is secondary and derived from the arsenopyrite, though possibly through the action of hypogene solutions. The orpiment has been derived from the realgar through the oxidation of a part of the arsenic.

The character of the ore changes greatly to the westward along the strike of the limestone bed. Arsenopyrite is not present in the quartz, and realgar and orpiment are no longer found. Stibnite is present only in one other deposit. Free gold, lacking in the White Caps ore, is found farther to the westward, fluorite and leverrierite become increasingly important gangue minerals, and minor adularia is present.

It is possible that three periods of mineralization are represented in the limestone ores; one marked by coarsely crystalline white calcite, which may have followed the granodiorite intrusion, and if so is of late Cretaceous or early Eocene age; the second, which introduced the quartz, arsenopyrite, pyrite and gold, together with the fluorite and leverrierite, is of later date, but prior to the most recent faulting; and the third, characterized by the stibnite and the realgar of the eastern part of the district, is still younger.

U. S. Geological Survey,
Washington, D. C.