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THE GOLD QUARTZ VEINS OF GRASS VALLEY, CALIFORNIA

BY

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ABSTRACT

The gold quartz veins in the vicinity of Grass Valley, Calif., have been actively mined since the fifties of the nineteenth century. Lindgren mapped the areal geology and studied the mines of the district in 1894, and the accompanying geologic map (pl. 1) is reproduced from his reports. Since then the principal mines have been deepened, many miles of underground workings have been opened, and new veins have been found.

The major geologic feature of the district is a body of early Cretaceous granodiorite 5 miles long from north to south and half a mile to two miles wide—probably the cupola of a great batholithic mass—which has intruded older sedimentary and igneous rocks and is itself cut by various dike rocks.

The oldest rocks of the district belong to the Calaveras formation, of Carboniferous age. Originally they were mainly clastic sediments but were converted into schistose or slaty rocks during the late Paleozoic orogeny and into a contact-metamorphic biotite gneiss by the intruding granodiorite during late Mesozoic time. The clay slates of the Mariposa formation, of Jurassic age, whose croppings are confined to a small part of the area, are relatively unaltered. The igneous rocks, other than granodiorite, include diabase, porphyrite, amphibolite schists, serpentine, gabbro, diorite, quartz porphyry, and many kinds of dike rocks.

Gold was discovered in the quartz veins of Gold Hill in 1850. Quartz mining was well established by 1857 and has continued without interruption to the present time. It is estimated that the quartz veins of the district have yielded more than $150,000,000 in gold. The Empire and North Star mines have each produced $30,000,000.

Mining conditions are unusually favorable. The temperature increases with depth at the rate of 1° F. for every 190 feet, and air temperature at the 9,000-foot level, 3,700 feet vertically beneath the surface, is 73°. Drifts and stopes in all the rocks except serpentine require little timbering, and rock bursts have not become serious at the depth attained. The mines are dry except in the upper levels, and pumping presents no difficulties. The mine waters contain principally calcium bicarbonate and sulphate.

Structurally the veins fall into two groups—those of the granodiorite area, with gentle dips averaging 35°, and those of the serpentine area, which are much steeper. Most of the veins in the granodiorite area strike north, parallel to the long axis of the granodiorite body. Others strike northwest, parallel to the diabase contact at the horizon at which they enter the granodiorite. The veins of the serpentine area strike northwest and have dips ranging between 50° and 70°. The most productive veins in both areas dip into the granodiorite with converging projected dips.

The veins fill minor thrust faults that occur within fracture zones of variable width and degree of shattering. In the granodiorite area the maximum measured reverse displacement was 20 feet, but in the serpentine area the displacement may be much greater.

Quartz is the principal vein mineral. The chief textural types are (1) comb quartz that forms crustifications and lines vugs; (2) massive milky quartz that has a granular texture with many sharp crystal faces and has not undergone deformation; (3) sheared quartz developed with little or no dilation of the vein fracture and commonly showing ribbon or shear-banding structures; and (4) brecciated quartz formed where vein movement dilated the interwall space. Few of the larger veins have only a single generation of quartz, and in places three or four generations are recognizable.

Gold occurs both in quartz and in cracks in broken sulphides, principally pyrite. Although much "specimen ore" has been found in the district, the average gold content of the ore mined in the past has been between 0.25 and 0.5 ounce to the ton.

An important structural feature in the district is the group of "crossings," vertical or steeply dipping fractures that strike northeast, about normal to the long axis of the granodiorite body. In places they are simple fractures; elsewhere they form sheeted fracture zones several feet wide. Some are tightly closed; others are open and form watercourses. Some have gouge; others have none. In contrast to the veins, few crossings contain quartz. They are significant structural features in an economic sense because they commonly bound ore shoots. By breaking the veins into segments, each of which has opened or closed more or less independently of the adjacent segments, the crossings have permitted mineralization in certain open segments, whereas others, which were closed, remained barren.

Two main stages of primary or hypogene mineralization are recognized—(1) a hypothermal stage, represented by one vein and one mineralized crossing, in which magnetite, pyrrhotite, pyrite, and specularite were deposited; (2) a mesothermal stage, in which the gold quartz veins were formed. The mesothermal stage is further divided into two substages—an older one, in which quartz is the principal gangue mineral, and a younger one, marked by the deposition of carbonates. Pyrite and arsenopyrite, deposited in the quartz substage, are the earliest sulphides of the gold quartz veins. Sphalerite, chalcopyrite, and galena are somewhat later. Gold is commonly associated with galena and is contemporaneous with it. The principal minerals of the carbonate substage are ankerite, calcite, and chalcedony. Sericite and chlorite were deposited through both substages. No secondary or supergene minerals have been noted except limonite, calcite, and gypsum, which are now being deposited in the oxidized zone.

The distribution of gold in the ore shoots is extremely erratic, and assays of adjacent vein samples commonly differ widely. Some ore shoots have a pitch length of several thousand feet, but most are much smaller. There has been no recognizable change in the character of the vein fractures nor in the occurrence or distribution of gold through a vertical range of nearly 4,000 feet, and there is no reason to suppose that the present mining depth has approached the bottom of the gold ores.

Adjacent to vein and crossing fractures the wall rocks are highly altered. Ankerite, sericite, and pyrite have replaced all the original rock-forming minerals. Lesser amounts of chlorite and epidote have been formed. The chemical changes in the wall rocks consisted mainly of the introduction of carbon dioxide, potassium, and sulphur and the removal of silica and sodium. The wall rock has not been replaced by quartz.

From the intersecting relations of dikes, crossings, and veins it can be established that both gently dipping fractures of the vein type and steeply dipping fractures of the crossings were opened before the last of the postgranodiorite dikes were intruded; that vein fissures were offset by crossings and crossings by veins before quartz deposition began; and that offsetting in both directions recurred during quartz deposition and continued after vein filling had ceased.

Several hypotheses to account for the origin of the fracture systems have been considered. Although the early history of the veins prior to the time of regional compression that is re-

corded in the fractured vein filling has not been completely reconstructed, it is concluded that the quartz was deposited by dilute aqueous solutions in open fissures. The suggestions that prequartz fissures have been widened by telluric pressure, force of growing crystals, or replacement have been rejected. The vein-depositing solutions are believed to have been wholly of magmatic origin, as no evidence could be found in support of the hypothesis that the silica in the quartz veins was derived from the wall rocks.

The mines of the district are described in the final part of the report.

INTRODUCTION

Location.—Grass Valley, a thriving gold-mining town in northern California, is on the western slope of the Sierra Nevada at an altitude of 2,500 feet, about 50 miles by air line northeast of Sacramento and 10 miles northwest of Colfax, the nearest station on the main line of the Southern Pacific Railroad. In 1930 Grass Valley had a population of 3,817, but with renewed activity in gold mining since that time the population has appreciably increased. Four miles northeast of Grass Valley is Nevada City, the county seat of Nevada County. Paved highways extend from Grass Valley to Auburn and Colfax, both on the transcontinental U. S. Highway 40.

The Grass Valley quadrangle is bounded by parallels 39°10′22″ and 39°13′50″ and meridians 121°01′35″ and 121°05′05″. It is 3.11 miles wide from east to west and 3.96 miles long from north to south. The area was surveyed in 1891 on a scale of 1 to 14,400, or about 4½ inches to the mile. It lies wholly within the Smartsville quadrangle, which has been mapped on the scale of 1 to 125,000 or about 2 miles to the inch.

The relative positions of the Alleghany, Nevada City, and Grass Valley districts and the Mother Lode are shown in figure 1.

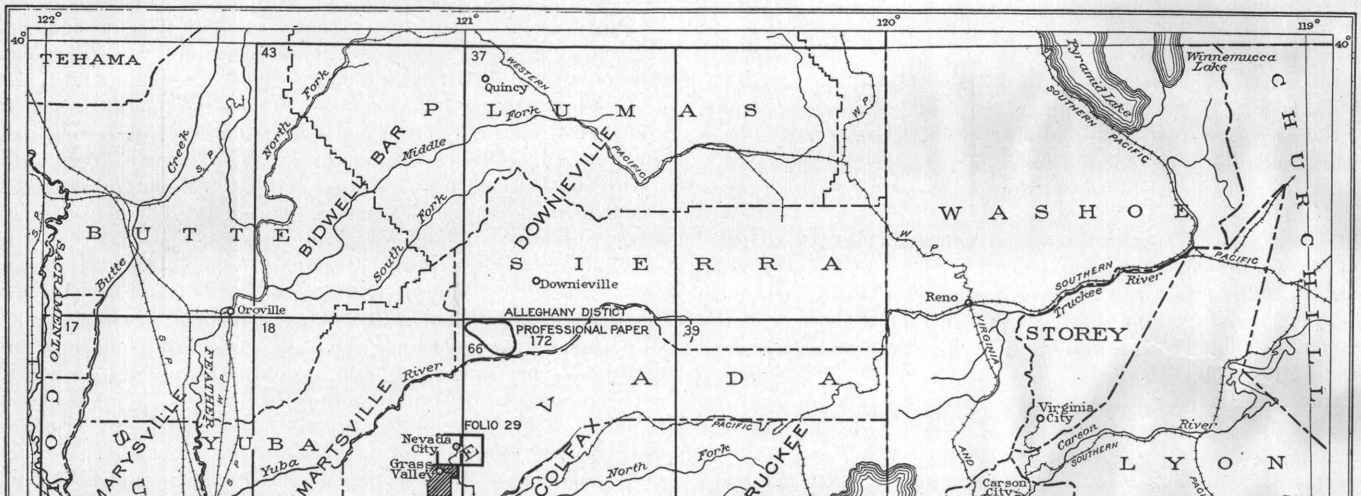

FIGURE 1.—Map showing location of the Grass Valley quadrangle, California. Quadrangles described in geologic folios are indicated by numbers in the upper left corner and names running diagonally. The areas shown on detailed maps—the Alleghany district (Professional Paper 172), the Nevada City area (Folio 29), and the Mother Lode belt (Professional Paper 157)—are outlined.

Previous work.—The earlier reports on the Grass Valley district are mainly mine descriptions. Only the most important writings prior to 1895 are included in the following list:

Browne, J. R., Report on the mineral resources of the States and Territories west of the Rocky Mountains, Washington, 1867 and 1868. Contains notes on mines in the district.

Bean, E. F., Bean's history and directory of Nevada County, Nevada City, 1867. Excellent historical data and detailed notes on production and ownership of many veins.

Raymond, R. W., Report on the mineral resources of the States and Territories west of the Rocky Mountains, vols. 1 to 8, Washington, 1869–77. Notes on mines in the district.

Burchard, H. C., Report of the Director of the Mint upon the statistics of the production of the precious metals in the United States, 1881–84. Production of Grass Valley mines.

Reports of the State mineralogist, vols. 1 to 12, Sacramento, 1880–1895. Notes on mines in the district.

Brief notes and scattered production data are contained in other publications, among them the Nevada County Mining Review.

In 1895 was published the Smartsville folio, by Lindgren and Turner and in 1896 Lindgren's excellent report on the gold quartz veins and his Nevada City Special folio appeared. Both of these works have provided invaluable aid and constant inspiration to the mining activity of the district. Later, Lindgren's Colfax folio and his report on the Tertiary gravels were issued. A list of Lindgren's principal contributions to the geology of the district follows:

Lindgren, Waldemar, and Turner, H. W., Geol. Survey Geol. Atlas, Smartsville folio (No. 18), 1895.

Lindgren, Waldemar, Characteristic features of California gold quartz veins: Geol. Soc. America Bull., vol. 6, pp. 221–240, 1895; Min. and Sci. Press, vol. 70, pp. 181–182, 213–214, and 244, 1895.

Lindgren, Waldemar, The gold quartz veins of Nevada City and Grass Valley districts, Calif.: Geol. Survey 17th Ann. Rept., pt. 2, pp.1–266, 1896.

Lindgren, Waldemar, Geol. Survey Geol. Atlas, Nevada City Special folio (No. 29), 1896.

Lindgren, Waldemar, Geol. Survey Geol. Atlas, Colfax folio (No. 66), 1900.

Lindgren, Waldemar, The Tertiary gravels of the Sierra Nevada of California: Geol. Survey Prof. Paper 73, 1911. (The geologic map accompanying this report was reprinted in 1935.)

A list of geologic papers relating to the area published since Lindgren's time is given below.

Hoover, H. C., Some notes on crossings; Min. and Sci. Press, vol. 72, pp. 166–167, 1896.

MacBoyle, Errol, Mines and mineral resources of Nevada County: State Mineralogist Rept. 1917–18, 270 pp., California State Mining Bureau, 1919. Lists all active and many inactive mines in Nevada County in 1916 and gives data on geology, production, and development.

Howe, Ernest, The gold ores of Grass Valley, Calif.: Econ. Geology, vol. 19, pp. 595–621, 1924. Howe for many years was consulting geologist to the North Star Co. He advanced the theory that the Grass Valley veins were formed mainly by replacement of the wall rocks.

Logan, C. A., Sacramento field division; Nevada County: California Dept. Nat. Resources, Div. Mines, Rept. 26 of State Mineralogist, pp. 90–137, 1930. Lists mines active in Nevada early in 1929 and gives notes on geology, mining development, and production.

Knaebel, J. B., The veins and crossings of the Grass Valley district, California: Econ. Geology, vol. 26, pp. 375–398, 1931. A petrographic study of vein and crossing filling, condensed from an E. M. thesis with the same title, Stanford University, 1930.

Loofbourow, R. L., The economic geology of no. 2 vein, North Star mine, Grass Valley, Calif.: E. M. thesis, Stanford University, 1931. Structural and petrographic study of a portion of the North Star mine.

Johnston, W. D., Jr., Geothermal gradient at Grass Valley, Calif.: Washington Acad. Sci. Jour., vol. 22, pp. 267–271, 1932.

Johnston, W. D., Jr., and Cloos, Ernst, Structural history of the fracture systems at Grass Valley, Calif.: Econ. Geology, vol. 29, pp. 39–54, 1934.

Johnston, W. D., Jr., Vein-filling at Nevada City, Calif.: Geol. Soc. America Bull., vol. 49, pp. 23-34, 1938.

Farmin, Rollin, Dislocated inclusions in gold quartz veins at Grass Valley, Calif.: Econ. Geology, vol. 33, pp. 579–599, 1938. Attributes dislocated vein inclusions to "thrust from an injected, vein-forming solution, which forcibly entered rock fractures and spread apart their walls." Discussion by W. A. Wiebenga, idem, vol. 34, pp. 342–346, 1939.

In addition several papers on mining methods have been published by the American Institute of Mining and Metallurgical Engineers, and numerous short articles recounting new or renewed mining activity in the district have appeared in the mining journals. Mineral Resources of the United States, a yearly volume, published by the Geological Survey from 1882 until 1923 and by the Bureau of Mines since, has contained many data on production. This series of volumes was succeeded by the Minerals Yearbook in 1932. References to many of the shorter articles are given in the body of this report.

Present investigation.—In 1929 G. F. Loughlin, chief of the metals section, Geological Survey, and W. W. Bradley, State mineralogist, discussed the possibility of studying the underground geology of the district made accessible by mining developments since Lindgren's time. W. A. Simkins, western manager of the Newmont Mining Corporation, which had recently acquired the Empire and North Star mines, immediately offered free access to the properties of his company and facilities for office work. It was decided that the restudy of the district should be undertaken by the Geological Survey, and the task was assigned to me. The California Division of Mines cooperated in the work by furnishing the services of R. L. Loofbourow, who ably and enthusiastically assisted me during the summers of 1930 and 1931. In those years a total of 10 months was spent in the field. Practically all of this time was devoted to underground studies, and only a few days was spent in surface mapping. In the summer of 1934 the active mines were revisited and most of the workings, opened since 1931, were examined. Again, in 1938, I spent a few days in the district.

The purpose of this report is to present data made accessible by underground mining development since 1894 and so to supplement Lindgren's report of 1896. When he worked in the district both the North Star and the Empire mines bottomed on the 2,400-foot level. In 1938 the Empire has been followed on the incline to the 7,000-foot level and the North Star to the 9,800-foot level.

The only mine of major importance to which access was not given is the Idaho-Maryland, which differs from the mines to the south in the character of the wall rock and in many features of mineralization. The treatment of problems pertaining to the serpentine area is correspondingly incomplete.

Lindgren's geologic map of the Grass Valley and Brunswick quadrangles is reproduced here with only a few minor changes (pl. 1). Shafts have been revised to 1934.

In this investigation nothing was done on the Tertiary rocks, which include the auriferous gravel channels, and only a very brief summary of previous knowledge of them is here given.

Acknowledgments.—To Professor Lindgren I am indebted for many of the basic data and explanations of many of the geologic processes discussed in this report. I have drawn more heavily upon his work than it is possible to acknowledge adequately by page references alone. After considering several alternative tectonic explanations for the Grass Valley structure, and some of them with much enthusiasm, I find myself at last convinced that Lindgren's explanation of 1896, that the vein fracture developed as a result of regional compression, is the correct one. Similarly, by a roundabout route, I have accepted his explanation for vein filling. Such wanderings from the pointed way cannot be recalled without a tinge of chagrin, which detracts nothing from my admiration of his geologic insight.

My colleagues on the Geological Survey have generously contributed many suggestions and much needed and helpful criticism at all stages of the work. H. G. Ferguson started me in the field and in the course of the field work visited me from time to time. G. F. Loughlin, W. T. Schaller, James Gilluly, C. S. Ross, C. E. Van Orstrand, R. C. Wells, H. C. Spicer, and George Steiger have aided in various phases of the work.

Dr. W. D. Urry, of the Massachusetts Institute of Technology, determined the age of some of the Grass Valley rocks by the helium method. Dr. Ernst Cloos, of Johns Hopkins University, visited the district and has heartily cooperated in studies of the structural history of the granodiorite body and the vein and crossing systems. As my introduction to the camp, I am indebted to the late Dr. Ernest Howe for a stimulating week end at his home in Litchfield, Conn., devoted to discussion of the geology of the North Star mine.

Cordial thanks are due to the mining engineers of Grass Valley, who lent hearty assistance in many ways. To Messrs. F. W. Nobs and John R. C. Mann, of the Empire Star; Fred Searls, Jr., W. A. Simkins, and A. F. Duggleby, of the Newmont Mining Corporation; Leland Wincapaw and Wallace Butler, of the Golden Center; H. R. Plate and H. F. Lynn, of the Spring Hill; T. S. Davey, of the Phoenix; Michael Brock, of the Boundary; and A. B. Foote, F. M. Miller, and E. C. Uren, I am especially indebted.

Many mining geologists have mapped portions of the mines of the district, and their maps and reports were made available to me. Among them are reports by Louis Janin, Guy Bjorge, Ernest Howe, Ira B. Joralemon, J. A. Burgess, H. F. Lynn, J. B. Knaebel, and A. F. Duggleby. Free use was made of their data in compiling geologic mine maps for this report.

In many respects the task of preparing this report has been an editorial one, for information has been collected from many sources and then supplemented by my own observations.

A grant from the Penrose Fund of the Geological Society of America made possible the study of the mines of the adjoining Nevada City district in the summer of 1934 and permitted me to spend a few days underground at Grass Valley.

Topography.—From the crest of the northern Sierra Nevada near the California-Nevada line, where the average altitude is between 7,000 and 8,500 feet, the land surface slopes westward for 75 miles to the edge of the Sacramento Valley, only a few hundred feet above sea level. Grass Valley is two-thirds of the way down the slope, at an altitude of 2,500 feet. The top of Osborne Hill is 3,080 feet and the bed of Wolf Creek is 2,080 feet above sea level. These are the highest and lowest points in the Grass Valley quadrangle. For the most part the slopes are gentle, approaching steepness only on the western flank of Osborne Hill and in the valley of Wolf Creek, which enters the quadrangle near the northeast corner and flows southward with a fall of a little less than 100 feet to the mile.

Climate and vegetation.—The monthly mean temperature at Grass Valley ranges between 41.9° for January and 74.0° for July. Daytime temperatures in the summer commonly exceed 90°, but the nights are generally cool. The annual mean temperature is 56.4°. The months of July and August are usually without rain, and the maximum precipitation, averaging 10 inches, occurs in January. Snow seldom remains long on the ground. The annual mean precipitation is 51.37 inches.

The forty-niners found the region covered by a mature pine forest. Mining operations required timber, however, and by the late eighties the countryside had been stripped of its trees. Photographs of Grass Valley taken about 1880 show bare hillsides. Since then, second-growth forest has been permitted to develop over most of the quadrangle, and yellow pine trees 10 to 12 inches in diameter are rooted in mine dumps of the early days. A dense growth of manzanita fills the treeless areas.

The following table is compiled from the 1932 yearly summary volume of Climatological Data published by the Weather Bureau.

Monthly mean temperature and precipitation at Grass Valley

	Temperature (° F.)	Precipitation (inches)
January	41. 9	10. 90
February	44. 4	8. 58
March	47. 4	7. 85
April	52. 3	4. 23
May	58. 2	2. 21
June	62. 6	. 70
July	74. 0	. 04
August	73. 4	. 04
September	66. 8	. 84
October	58. 8	2. 65
November	49. 8	5. 60
December	43. 0	8. 44
Annual mean	56. 4	51. 37
Length of record in years	24	57

The digger pine (*Pinus sabiniana*), whose gray-green foliage is so sparse that it casts little or no shadow, is the principal tree growing on serpentine. As it stands in sharp contrast to the greener and more luxuriously foliated sugar and yellow pines, serpentine belts are commonly sharply delineated by it.

SUMMARY OF THE GEOLOGIC HISTORY OF THE NORTHERN SIERRA NEVADA

A summary of the geologic events in the Sierra Nevada in general and in the Grass Valley quadrangle in particular is given in the accompanying table.

The column on the Sierra Nevada is taken from a report by Matthes [1]

Little is known of the early Paleozoic history of the Sierra Nevada. In Tehama and Plumas Counties are quartzites, shales, and limestones of Silurian and Devonian age that rest on ancient metamorphic rocks.[2] Devonian and older sediments in the Klamath Mountains, to the northeast, bear witness to the existence, during the Paleozoic era, of a great Cordilleran geosyncline in which sediments were laid down through Mississippian time, at least. Sedimentation during the Mississippian epoch is recorded by the great thickness of slate, conglomerate, and limestone, constituting, with the associated Carboniferous igneous rocks, the Calaveras formation, which today is exposed throughout the length of the Sierra Nevada. Fossils have established the Mississippian age of parts of the Calaveras, but it is by no means certain that pre-Mississippian and possibly early Triassic rocks are not included in it.

In late Paleozoic or early Mesozoic time, the predecessor of the Sierra Nevada came into existence. Great thicknesses of sediments that had been accumulating in the Cordilleran trough were uplifted and strongly folded, and upon the Calaveras formation was impressed a type of regional dynamic metamorphism that distinguishes it from younger rocks. Knopf[3] has suggested that intrusions of diorite accompanied the late Paleozoic orogeny. Certainly much of the diorite shows greater foliation than the later granodiorite.

The absence of Lower Triassic sedimentary rocks in the northern Sierra Nevada records a time of erosion that was ended by subsidence of the land. In the Colfax quadrangle[4] at least 6,000 feet of shale and limestone of the Sailor Canyon formation was deposited in early Jurassic time. Taliaferro[5] has recently recognized a group of rocks of late Triassic or early Jurassic age composed of "tuffs, flows, and agglomerates with interbedded sediments of a very distinctive character. The sediments consist chiefly of red, green, and black radiolarian chert, red, black, and gray shales, tuffaceous sandstones and conglomerates, and impure limestones." The volcanic rocks he believes to be submarine extrusions.[6] To this sequence he gave the name "Tuolumne group."[7]

In late Jurassic time sedimentation over the submerged Sierra Nevada continued, and the black slates, sandstones, and conglomerates of the Mariposa formation were deposited. Contemporaneous with or closely following the deposition of the Mariposa sediments was a time of widespread volcanic activity. As the land again emerged, andesitic rocks—the diabase and porphyrite and their tuffs and breccias—were poured over the surface and intruded at shallow depths. Some of the diabase of the Grass Valley area, however, may belong to the Triassic or early Jurassic Tuolumne group of Taliaferro. The region was again subjected to orogenic stresses, and the rocks were compressed into northwestward-trending isoclinal folds. As pointed out by Knopf [8] the metamorphism imposed upon the rocks by the Cordilleran revolution was of the feeblest kind. The Mariposa sediments were compacted and cemented, and some of the andesitic rocks acquired schistosity, but the chemical and physical changes were much less severe than those imposed upon the Calaveras formation in the earlier Paleozoic orogeny.

[1] Matthes, F. E., Geologic history of the Yosemite Valley: U. S. Geol. Survey Prof. Paper 160, p. 23, 1930.

[2] Diller, J. S., Geology of the Taylorsville region, Calif.: U. S. Geol. Survey Bull. 353, pp. 14–19, 1908. Hinds, N. E. A., Geologic formations of the Redding-Weaverville districts, northern California: California Jour. Mines and Geology, vol. 24, pp. 85–90, 1933.

[3] Knopf, Adolph, The Mother Lode system: U. S. Geol. Survey Prof. Paper 157, p. 9, 1929.

[4] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Colfax folio (no. 66), pp. 2–3, 1900.

[5] Taliaferro, N. L., A contribution to the stratigraphy of the bedrock complex of the Sierra Nevada of California: Cordilleran section, Geol. Soc. America, List of papers with abstracts presented at Pasadena, 1931, pp. 18–20; shorter abstract in Geol. Soc. America Bull., vol. 43, pp. 233–234, 1932.

[6] Taliaferro, N. L., Bedrock complex of the Sierra Nevada, west of the southern end of the Mother Lode [abstract]: Geol. Soc. America Bull., vol. 44, pp. 149–150, 1933.

[7] As this name had previously been used by Calkins for other rocks, Taliaferro, in a personal communication dated February 18, 1935, has proposed the substitute name "Amador group."

[8] Knopf, Adolph, op. cit., p. 10.

Tabular summary of geologic events in the Sierra Nevada and in the Grass Valley quadrangle

Era	Period	Epoch	Nature of events in the whole Sierra Nevada [1]	Nature of events in the Grass Valley quadrangle
Cenozoic.	Quaternary.	Recent.	Postglacial time. Return to normal climatic conditions.	
		Pleistocene.	The great ice age. The higher parts of the range are repeatedly mantled by glaciers.	Gold placers are formed in the stream channels.
	Tertiary.	Pliocene.	Renewed vigorous tilting, accompanied by strong fault movements along its eastern margin, causes the Sierra Nevada to stand forth as a lofty block range with a steep eastern front. Period of relative stability. Occasional minor crustal movements and volcanic outbreaks.	Erosion removes most of the andesite and again exposes the older rocks.
		Miocene.	The region is tilted to the west and attains mountainous height at its eastern margin. Volcanic eruptions begin anew, and the northern Sierra Nevada is covered by successive flows of andesitic lava and mud.	Flows of andesitic tuff and breccia cover the quadrangle.
		Oligocene.	Prolonged interval marked by minor warpings of the earth's crust, up and down. The land is subject to continuous erosion and the rhyolitic materials are mostly worn away.	The land surface is eroded, and later gold-bearing gravels are deposited in the stream channels.
		Eocene.	This region, together with the country east of it, is slowly upwarped to moderate heights. Volcanoes burst forth in the northern Sierra Nevada and cover the land repeatedly with rhyolitic lava, mud, and ash.	Beds of rhyolitic ash are deposited to the north of the Grass Valley quadrangle. Erosion is resumed and continued to a depth which exposes the granodiorite. Gold-bearing gravels are concentrated in the stream channels.
Mesozoic.	Cretaceous.		The mountain ranges are worn down gradually, and the region as a whole is reduced to a lowland. The bulk of the sedimentary rock, several thousand feet in thickness, is carried away by the streams, and the granite is uncovered over large areas.	Gold-quartz veins are formed. The Calaveras formation is subjected to contact metamorphism. Some diabase and porphyrite are altered into amphibolite schist. Peridotite (serpentine), diorite, and granodiorite are intruded.
	Jurassic.		The new sediments, together with remnants of the old, are folded and crumpled into parallel, northwestward-trending mountain ranges. Molten granite invades the folds from below. More sediments are laid down as the sea bottom progressively sinks.	South of Grass Valley, shales and sandstones of the Mariposa formation are deposited.
	Triassic.		The mountains are slowly worn down to hills. The land finally sinks below the sea and new sediments are deposited.	Flows and near-surface intrusions of andesitic rocks (diabase and porphyrite) take place. The land is eroded.
Paleozoic.	Carboniferous.	Permian.	The sediments are uplifted and folded into mountain ranges.	Regional dynamic metamorphism converts the shales and sandstones of the Calaveras formation into phyllites and quartzites.
		Pennsylvanian and Mississippian.		Volcanic rocks are metamorphosed into amphibolite schist.
	Devonian.		Sediments accumulate to thicknesses of thousands of feet on the floor of the Pacific Ocean.	Shales, sandstones, limestones, and cherts, now comprising the Calaveras formation, are deposited. Some volcanic rocks are intruded into and interbedded with the sediments.
	Silurian.			
	Ordovician.			
	Cambrian.			No record is preserved.
Proterozoic.	Pre-Cambrian.		Nothing definite known.	No record is preserved.

[1] After Matthes, F. E., Geologic history of the Yosemite Valley: U. S. Geol. Survey Prof. Paper 160, p. 23, 1930.

Intrusion of ultrabasic rocks, followed by gabbro, diabase, granodiorite, granite, and aplite, marked the climax of the Cordilleran revolution. Granodiorite was intruded in tremendous batholithic masses that now form the backbone of the high Sierra. On the western slope smaller masses of granodiorite are satellitic to the main mass. The earlier formations were shoved aside and possibly in part assimilated, and contact-metamorphic zones were developed in the sedimentary rocks. From the last emanations of the granitic intrusives were formed the gold quartz veins of the Sierra Nevada.

The Cordilleran revolution was completed in late Jurassic or early Cretaceous time, and the rocks affected by it were classed in the gold-belt folios, as the †Bedrock series,[9] in contrast to the later Cretaceous, Tertiary, and Quaternary deposits, which were grouped as the †Superjacent series.

At the end of the Cordilleran revolution the Sierra Nevada was again a mighty mountain range, but erosion, continuing through late Cretaceous time, removed much of the cover of metamorphic rocks, laid bare the granodiorite batholith, and reduced the region to a lowland. (See table p. 6.)

In the Eocene epoch the Sierra Nevada was slowly uplifted. Uplift along great faults on its eastern edge permitted steepening of the western slope as the mountain block was tilted toward the west. The westward-flowing master streams cut deep valleys in which gravel and gold eroded from quartz veins in the older rocks were deposited. Volcanism broke out anew, and rhyolitic ashes, tuffs, and flows buried many of the gold-bearing gravel channels. Erosion and the accumulation of auriferous gravel alternated with outpouring of rhyolite.

Fossil leaves of Eocene age are preserved in ash and shale beds overlying some of the early gravels, and later gravels contain floras of Miocene age.[10] Over much of the Sierra the rhyolite was completely removed by the end of the Oligocene epoch.

In Miocene time volcanism was resumed. Flows of andesite, andesitic tuffs, breccias, and mud were poured out over the land surface, burying the older rocks. Eruptions were recurrent, for stream-channel sands and gravels, some of which are gold-bearing, are interbedded with the andesite.

In late Tertiary time the Sierra Nevada was once again uplifted and tilted to the west.

Since Miocene time the dominant geologic process in the Sierra Nevada has been erosion. Over much of the area the andesite cover has been stripped from the older rocks, Tertiary gravels have been reworked, and the gold deposited in later stream channels. Formations of the †Bedrock series have been worn down and quartz veins that formerly extended far above the present land surface have added their gold to the placer deposits. Minor warping of the mountainous block continued throughout the Tertiary period and was perhaps strongest at its end. In the great Pleistocene ice age snow fields covered the high mountains, and glaciers descended the principal valleys, altering their shape and depositing moraines. With the return to a temperate climate the normal erosion processes, which are operating today, were resumed.

Such, briefly, is a generalized geologic history of the Sierra Nevada as we know it today. Many known details have been omitted, and many important problems remain unsolved.

ROCK FORMATIONS

CALAVERAS FORMATION

General features.—The Calaveras formation in the Grass Valley quadrangle occurs in two narrow belts striking to the northwest.

The western belt occupies a long, narrow strip that extends from north to south for a distance of 20 miles, crossing the western border of the quadrangle. It is composed of soft fissile argillite and contains abundant chert, probably derived from limestone lenses. As pointed out by Lindgren,[11] the Devils Punch Bowl—a circular undrained depression at the western edge of the quadrangle—is probably a sinkhole developed in one such limestone bed. Surface exposures are poor, and no accessible mine workings cut this belt of the Calaveras formation.

The eastern belt, which crosses the north-central part of the quadrangle, is composed of gray to black schistose rocks including phyllites, slate, quartzites, quartz-biotite schists, and related rocks. Originally clastic sediments, they have been subjected to regional pressure and to heat, with the resultant loss, in varying degree, of their original character. Many of the fine-grained argillaceous rocks have been converted into dense hornfels (see pl. 3, *A*), and fine-grained sandstones show mortar structure. Coarse-grained sandstones show mild shearing, and in some the quartz grains have been stretched and cemented by biotite.

Surface exposures of the Calaveras formation are poor, but excellent underground exposures are found in the upper workings at the north end of the Empire mine, particularly along the 1,100-foot level crosscut, which extends across the Calaveras belt. In this crosscut and in the old workings above the 1,100-foot level a great variety of dark-gray to black quartzitic phyllites are exposed. They are made up of angular quartz fragments, 0.2 to 1 millimeter in diameter, embedded in a groundmass composed of muscovite, amphibolite, zoisite, epidote, carbonates, and quartz. Many of the larger quartz fragments have been recrystallized into rosettes whose individual grains average 0.02 to

[9] A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in publications of the Geological Survey.

[10] Chaney, R. W., Notes on occurrence and age of fossil plants found in the auriferous gravels of Sierra Nevada: California Dept. Nat. Resources, Div. Mines, Rept. State Mineralogist, vol. 28, nos. 3 and 4, pp. 299–302, 1932.

[11] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 88.

0.06 millimeter in diameter, and most of the quartz grains show strain figures. Bedding is frequently recognizable by change in the grain size.

Carbonaceous clay slates breaking into rough plates occur near the northeast end of the crosscut. Photomicrographs of Calaveras rocks are shown in plate 3.

All these rocks show some traces of schistosity striking N. 20° to 30° W. in conformity with the regional grain of the Calaveras formation. This schistosity is more conspicuous in the weathered croppings, however, than in underground exposures.

Although no fossils have been found in the Grass Valley area, *Clisiophyllum gabbi* Meek, *Lithostrotion whitneyi*, and *Pleurotomaria* sp., of Mississippian age, occur to the southeast near Colfax,[12] along the projected strike of the formation. In the Colfax folio the rocks corresponding to the Calaveras were subdivided into several formations. The Calaveras rocks of the Grass Valley quadrangle correspond to the youngest of these, the Clipper Gap.

Contact metamorphism.—On the borders of the granodiorite the more quartzitic beds of the Calaveras formation have been converted into a dense quartzite or schist that contains much new dark-brown biotite, the variety depending upon the original grain size. This contact-metamorphic zone averages 150 to 300 feet in width. The biotite-bearing rock is readily recognized by the pink to violet-brown luster of freshly broken surfaces. Under the microscope the biotite foils are seen to occupy spaces between the clastic grains. In some of these rocks the biotite has a random distribution; others are schistose with elongated clastic grains cemented by biotite with parallel extinction. Plate 3, *C*, shows such a biotite schist from the dump of the Crown Point mine.

The contact-metamorphic rocks are well exposed in the 4,600-foot level crosscut at the north end of the Empire mine, which traverses several apophyses of the main mass of intrusive granodiorite.

Lindgren [13] has described a quartz-tourmaline contact-metamorphic rock enclosed in porphyrite a short distance west of the Sciota shaft.

The granodiorite appears to be the only intrusive that produced consistent contact-metamorphic alteration of the Calaveras formation, although contact breccias occur along the contact between Calaveras and porphyrite on the western margin of the Calaveras area, south of Wolf Creek. This brecciation, however, was almost wholly mechanical and indicates a much less intense degree of metamorphism than that produced by the granodiorite.

MARIPOSA FORMATION

Lindgren has mapped a band of black clay slates, exposed on each side of the upper course of Wolf Creek near the old Washington mine, as the Mariposa formation of Jurassic age. Interbedded with the slates are tuffaceous beds containing porphyrite and fragments of siliceous argillite identical with argillite of the Calaveras formation exposed in the vicinity of the Federal Loan mine, in the Banner Hill quadrangle. Although the main belt of the Mariposa formation, which Lindgren has mapped in the Colfax quadrangle, is cut off by igneous rocks a short distance northwest of the town of Colfax, the Grass Valley exposures are on the projected strike of the main belt. Because of their concordance in strike, the relatively unaltered character of the slates in Grass Valley, their associated tuffs, and their included fragments of Calaveras rocks, Lindgren was convinced that the slates on upper Wolf Creek were younger than the more abundant slates of the Calaveras and assigned them to the Mariposa formation.

PRE-TERTIARY GREENSTONES

General features.—Pre-Tertiary gray-green to greenish-black rocks of varied texture and general andesitic composition are widely distributed throughout the Sierra Nevada. In the gold-belt folios Lindgren and Turner mapped them as diabase, porphyrite, and amphibolite schist. Ransome [14] used the name "meta-andesite" for the nonschistose greenstones. Although the rock name "porphyrite"[15] is not in good repute among petrographers and "diabase"[16] is not truly descriptive of all the rocks so named, the terms are so firmly implanted in the descriptive petrographic literature of the Sierra Nevada and convey such definite concepts to students of Sierra Nevada rocks that their retention appears to be both necessary and desirable.

The diabases and porphyrites form one of the most conspicuous petrographic units of the quadrangle. They include all the "greenstones" with the exception of the amphibolite schists and the dikes of intermediate to basic composition which are known definitely to cut the granodiorite.

These rocks are extremely variable in texture and in mineral and chemical composition, but two principal types are readily distinguished—(1) the diabases, including normal and porphyritic diabase; and (2) the porphyrites or porphyritic andesites. In addition to these two types there is a series of transitional rocks of composition and texture intermediate between them, as well as their tuffs and contact breccias.

Mineralogically the diabasic rocks are composed essentially of plagioclase (oligoclase to labradorite) and augite, which may be replaced in whole or in part by hornblende. Quartz is present in some of them.

[12] Lindgren, Waldemar, Geol. Survey Geol. Atlas, Colfax folio (no. 66), p. 2, 1900. Moody, C. L., The breccias of the Mariposa formation in the vicinity of Colfax, Calif.: California Univ. Pubs. in Geology, vol. 10, no. 21, p. 386, 1917.

[13] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 88.

[14] Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Mother Lode district folio (no. 63), 1900.

[15] Grout, F. F., Petrography and petrology, p. 86, New York, McGraw-Hill, 1932. Knopf, Adolph, The Mother Lode system of California: Geol. Survey Prof. Paper 157, p. 15, 1929.

[16] Knopf, Adolph, idem.

Biotite, pyrite, pyrrhotite, ilmenite, titanite, and apatite are essential constituents. Secondary minerals are chlorite, epidote, zoisite, leucoxene, sericite, pyrite, and clay minerals. Some of the rocks are strongly albitized.

The following analyses are representative:

Analyses of diabase and quartz porphyrite

[H. N. Stokes, analyst]

	1	2	3
SiO_2	51. 01	53. 19	63. 39
Al_2O_3	11. 89	17. 12	16. 58
Fe_2O_3	[1] 1. 57	[1] 4. 35	1. 41
FeO	[1] 6. 08	[1] 5. 16	3. 08
MgO	8. 87	3. 98	2. 15
CaO	10. 36	9. 39	4. 76
Na_2O	4. 17	2. 79	3. 47
K_2O	. 15	. 28	2. 79
H_2O-	. 24	. 17	. 22
H_2O+	2. 09	1. 21	1. 87
TiO_2	. 98	1. 34	. 44
P_2O_5	. 17	. 13	. 14
MnO	Trace	Trace	Trace
BaO	--------	Trace	. 11
CuS	Trace	--------	--------
Cr_2O_3	. 04	--------	--------
FeS_2	1. 73	[2] . 94	--------
	99. 35	100. 05	100. 41

[1] Approximate only because of presence of sulphides.
[2] Calculated as FeS_2 but much Fe_7O_8 also present.

1. Diabase, with some albitization, 425 feet west of the reservoir above Maryland mine. Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 66.
2. Diabase, 3,000 feet north of the Omaha mine. Idem, p. 71.
3. Quartz porphyrite, New Ophir claim. Idem, p. 75.

These rocks crop out in three main belts—(1) the Brunswick area, a rough crescent just south of the Idaho-Maryland mine; (2) the Osborne Hill area, which forms a wide band extending from Wolf Creek to the southeast corner of the quadrangle; and (3) the North Star area, which extends north from the old North Star shaft. In addition to these three main areas there are two smaller outcrops south of the North Star mine and several diabase and porphyritic dikes in the Calaveras formation and in the serpentine north of Wolf Creek.

Diabase.—The diabases are dark-green to blackish granular rocks of fairly uniform character. Typical diabases have an ophitic texture (pl. 4, *A* and *B*) and are composed of plagioclase laths with interstititial augite or hornblende, which, in the coarser varieties, is readily recognized in the hand specimen. The grain size of the diabase is variable, ranging between 0.05 and 3.00 millimeters. In addition to those with characteristic ophitic or diabasic texture, some rocks of identical mineral composition are nearly granular and could more properly be called diorites. Others show inclusions of ilmenite or magnetite in poikilitic augite and feldspars.

Under the microscope the diabases are seen to be composed of plagioclase feldspars with the composition of andesine ($Ab_{25}An_{75}$ to $Ab_{50}An_{50}$), usually in long, well-shaped laths, with interstitial augite and some brown hornblende, which may replace the augite either wholly or in part. Many thin sections show secondary borders of albite around the andesine, and some show borders of brown hornblende around augite, suggesting deuteric replacement by the bordering minerals. In the more granular varieties of diabase both the augite and the plagioclase grains are rather rectangular and interlocked. Accessory minerals are magnetite, ilmenite, titanite, pyrite, and pyrrhotite.

All the diabase examined shows more or less hydrothermal alteration. Green uralitic hornblende and chlorite have replaced both augite and primary hornblende; sericite or paragonite and clay minerals cloud and locally have completely replaced the plagioclase; ilmenite is coated with leucoxene; epidote has formed both in the augite and in the feldspars; and near the veins much ankerite has been introduced.

Typical ophitic diabase, as well as the more granular varieties, occurs in the three major outcrop areas and is exposed in the upper workings of both the Empire and North Star mines. Normal diabase dikes occur in the Maryland serpentine area and in the Calaveras formation near the Idaho-Maryland mine. Unusually coarse-grained diabase was found on the Coe dump. Lindgren[17] describes an augite syenite from a point half a mile east of the Grass Valley railroad station which may be considered a facies of the diabase of the Maryland area.

Much of the diabase is porphyritic, containing phenocrysts of plagioclase, augite, or hornblende. Such rocks are transitional between the normal diabases and the porphyrites and might be classified with either, depending upon the degree of development of the porphyritic texture.

Porphyritic rocks more nearly allied with the diabases than with the porphyrites are of wide distribution in both the North Star and the Osborne Hill diabase areas and are cut by drifts in the upper parts of the Empire and North Star mines.

Porphyrite.—Under the rock name "porphyrite" are included medium- to dark-gray rocks of porphyritic texture with plagioclase phenocrysts. In mineral composition they are porphyritic andesites, but the name "porphyrite" as defined by Iddings [18] and used by Lindgren and Turner in the gold-belt folios is so firmly fixed in the descriptive petrography of the Sierra Nevada, and the mineralogic and textural concept conveyed by it is so definite that the abandonment of the term in favor of a more general rock name is unjustified.

Ransome's term "meta-andesite,"[19] though fittingly applicable to some of the Grass Valley porphyrites,

[17] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), pp. 68–70.
[18] Iddings, J. P., The eruptive rocks of Electric Peak and Sepulchre Mountain, Yellowstone National Park: U. S. Geol. Survey 12th Ann. Rept., pt. 1, pp. 582–583, 1891.
[19] Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Mother Lode district folio (no. 63), p. 3, 1900.

would exclude those that have retained their freshness and are unaffected by dynamic metamorphism.

Few specimens of porphyrite are completely fresh. The feldspars contain sericite, clay minerals, and carbonates; augite and primary hornblende have been altered to uralite, chlorite, epidote, and zoisite; and the ilmenite is coated with leucoxene. Much secondary pyrite, frequently in crystals as large as 5 millimeters square, has been introduced into both the porphyrite and the diabase.

There appears to be little uniformity in the distribution of the different varieties of porphyrite within the area. Hornblende porphyrite is found on the dump of the Rocky Bar mine; hornblende-augite porphyrite forms dikes in the Calaveras formation; quartz-hornblende porphyrite occurs in the Brunswick area; dikes of quartz porphyrite cut the diabase near the Orleans mine; augite porphyrite occurs east of the Golden Treasure shaft, in the Osborne Hill mine dump and near the Orleans mine; augite-plagioclase porphyrite crops out in Wolf Creek near the Omaha mine and is cut by the 1,900-foot level of the North Star mine and the upper levels of the Empire mine; and augite porphyrite with chlorite-filled vesicles is found in the Orleans dump.

Fragmental porphyritic rocks are present along the crest and on the east slope of Osborne Hill, and near its north end a dark-green porphyritic breccia with fragments of siliceous argillite crops out. In the Empire 1,100 level crosscut and in the levels above it the porphyrite is much brecciated and flow lines are common.

The porphyrites are extremely variable rocks. Some have a gray to black or green microcrystalline groundmass studded with small white phenocrysts of quartz or plagioclase feldspar, some have green to black phenocrysts of hornblende or augite, and others have phenocrysts of both plagioclase and hornblende or augite.

In thin section, under medium magnification, the groundmass is resolved into a granular to ophitic intergrowth of plagioclase laths with interstitial grains of augite, brown or greenish hornblende, and occasionally biotite. Accessory minerals are pyrite, pyrrhotite, magnetite, and ilmenite. A few specimens with very fine groundmass show traces of flow structure around the phenocrysts.

The plagioclase in the phenocrysts (andesine to labradorite) is generally the same as that in the groundmass except in the few specimens in which the groundmass contains later albite. The augite phenocrysts are stout and well formed. Many of them are surrounded by rims of brown hornblende. Few of the quartz phenocrysts, however, have well-defined crystal forms. As a rule they have corroded outlines that indicate some degree of resorption. The accessory minerals occur as inclusions in all the essential minerals.

Age of the diabase and porphyrite.—The diabase and porphyrite are younger than the Calaveras formation and older than the granodiorite. Lindgren [20] considers these rocks contemporaneous with and in part slightly later than the Mariposa formation. Similar rocks on the Mother Lode are intimately associated with the Mariposa.[21]

Concerning the method of emplacement of the diabase and porphyrite Lindgren [22] says:

> The frequent porphyritic character and especially the abundant presence of fragmental rocks characterize the group, in contrast to the granodiorite and the diorite-gabbro group, as surface eruptions, while the transition in granular diabases, on the other hand, tends to connect it with the intrusive rocks. It is probable that the group represents what is left of the extensive volcanoes which at the close of the Jurassic period were built up along the foothills of the Sierra Nevada. The erosion having removed the upper part, the remaining cores are exposed. The progressive eruptions of new material as the volcanic masses piled up will, to some extent, explain the close juxtaposition of rocks of intrusive and effusive types.

Dr. W. D. Urry,[23] of the Massachusetts Institute of Technology, using the helium method,[24] has determined the ages of three specimens of diabase from the 4,000 and 4,700 levels of the North Star mine to be 150 ± 8, 165 ± 8, and $170\pm$(?) millions of years. These determinations have the same limits as those for three specimens from the Triassic Palisade diabase at Kings Bluff, Weehawken, N. J., which gave ages of 155 ± 8, 165 ± 8, and 165 ± 9 millions of years.[25]

Although these age determinations are perhaps inadequate to establish the age of the diabase of the North Star mine definitely as late Triassic rather than Jurassic, to which the diabase and porphyrite of the area had previously been assigned, Urry's dating undoubtedly suggests that the diabase examined might belong to the Triassic or early Jurassic Tuolumne group of Taliaferro.[26]

Since the paragraphs above were written, some inconsistencies in the helium method have been found. In general, the ages obtained by the method are thought to be too low. At the present time several men are working on the method and until their investigations are completed the absolute ages obtained by helium ratios must be regarded as tentative, although relative ages appear to be generally correct.[26a]

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[20] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 57.

[21] Knopf, Adolph, The Mother Lode system of California: U. S. Geol. Survey Prof. Paper 157, pp. 14–15, 1929.

[22] Lindgren, Waldemar, op. cit., p. 57.

[23] Urry, W. D., and Johnston, W. D., Jr., Age of the Sierra Nevada granodiorite [abstract]: Geol. Soc. America Proc. for 1935, p. 114.

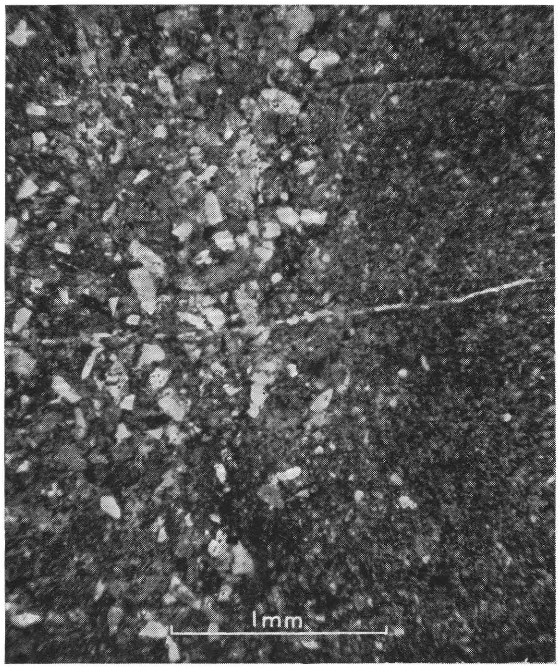
[24] Urry, W. D., The "helium method": Chem. Rev., vol. 13, pp. 305–343, 1933.

[25] Urry, W. D., Determination of the radium content of rocks: Jour. Chem. Physics, vol. 4, p. 47, 1936.

[26] Taliaferro, N. L., Bedrock complex of the Sierra Nevada west of the southern end of the Mother Lode [abstract]: Geol. Soc. America Bull., vol. 44, pp. 149–150, 1933.

[26a] Evans, R. D., Goodman, Clark, Keevil, N. B., and Urry, W. D., Work at the Massachusetts Institute of Technology, Exhibit 3 of the Report of the Committee on the Measurement of Geologic Time, 1937–38, pp. 57–70, National Research Council, Washington, 1938.

Evans, R. D., Goodman, Clark, Keevil, N. B., Lane, A. C., and Urry, W. D., Helium investigations, 4, Intercalibration and comparison in two laboratories of measurements incident to the determination of geologic ages of rocks [abstract]: Geol. Soc. America Bull., vol. 49, pp. 1879–80, 1938.

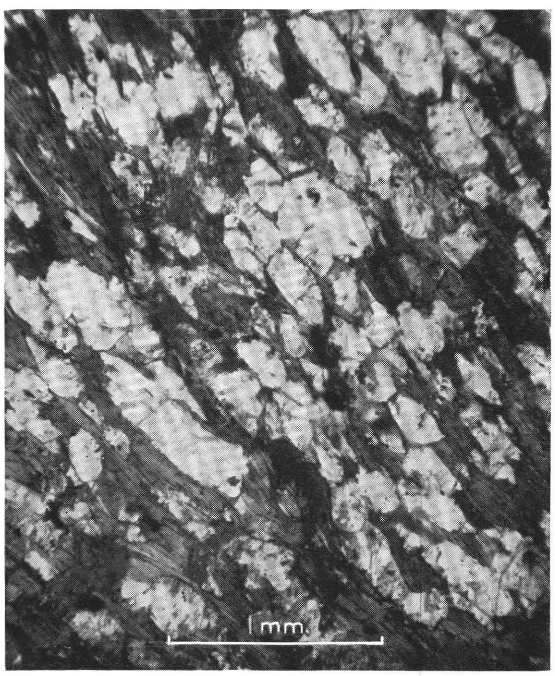


A. HORNFELS COMPOSED OF ANGULAR QUARTZ FRAGMENTS IN A GROUNDMASS OF MUSCOVITE, QUARTZ, EPIDOTE, ZOISITE, AND CHLORITE.

Shows two granulation zones of different grain size. Empire mine, 900-foot level, north drift.

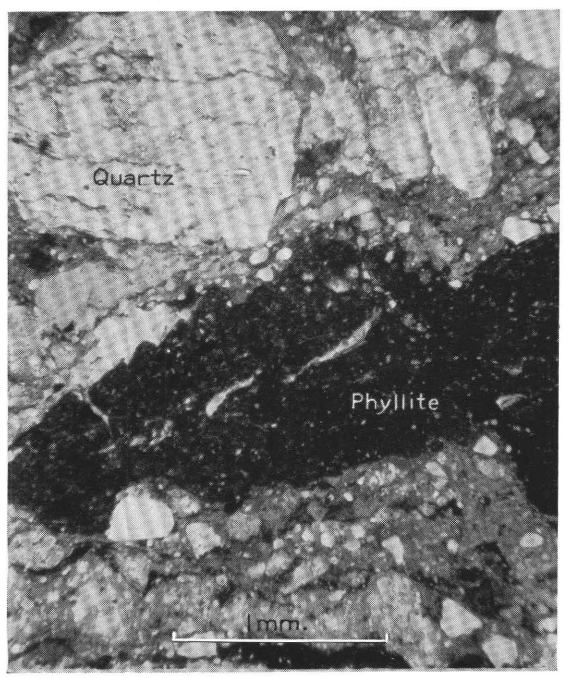
B. PHYLLITE COMPOSED OF ANGULAR QUARTZ WITH GROUNDMASS OF BIOTITE, CHLORITE, EPIDOTE, AND LIMONITE.

Empire mine, 1,100-foot level crosscut.



C. CONTACT-METAMORPHIC BIOTITE SCHIST COMPOSED OF SUBANGULAR QUARTZ GRAINS SURROUNDED AND CEMENTED BY REDDISH-BROWN BIOTITE IN PARALLEL ORIENTATION.

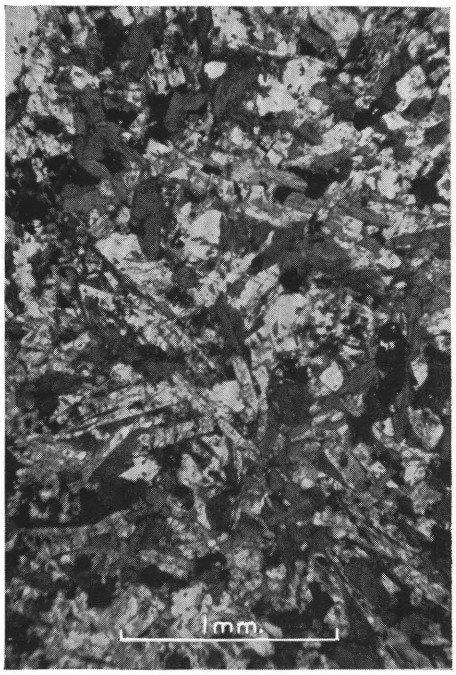
Crown Point mine dump.



D. BRECCIA CONTAINING FRAGMENTS OF PHYLLITE AND QUARTZ.

Empire mine, 1,100-foot level crosscut.

PHOTOMICROGRAPHS OF THE CALAVERAS FORMATION.

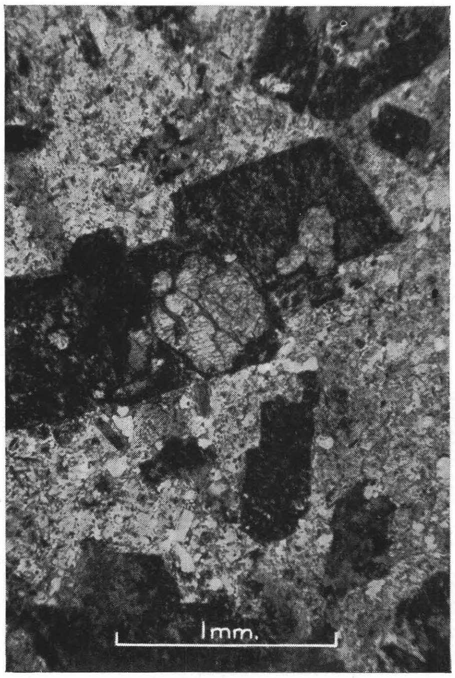


A. DIABASE FROM OLD NORTH STAR SHAFT.

Shows plagioclase and hornblende laths. Ophitic texture. One nicol.

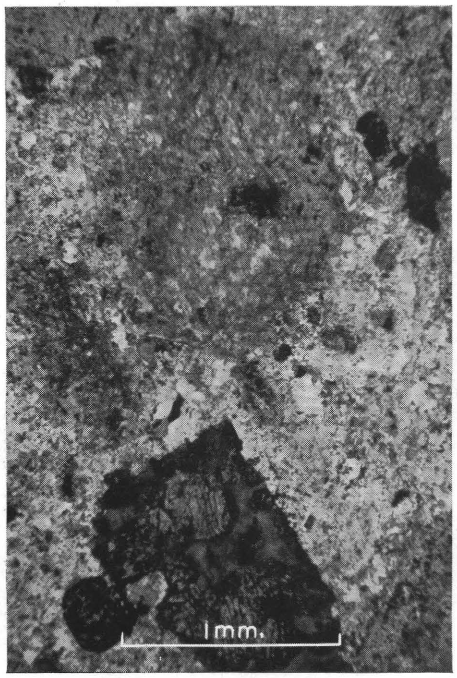
B. DIABASE FROM 3,400-FOOT LEVEL, Y VEIN, NORTH STAR MINE.

Shows plagioclase laths, chloritized hornblende, and pyrite. Ophitic texture. Crossed nicols.



C. PORPHYRITE FROM BED OF WOLF CREEK NEAR OMAHA MINE.

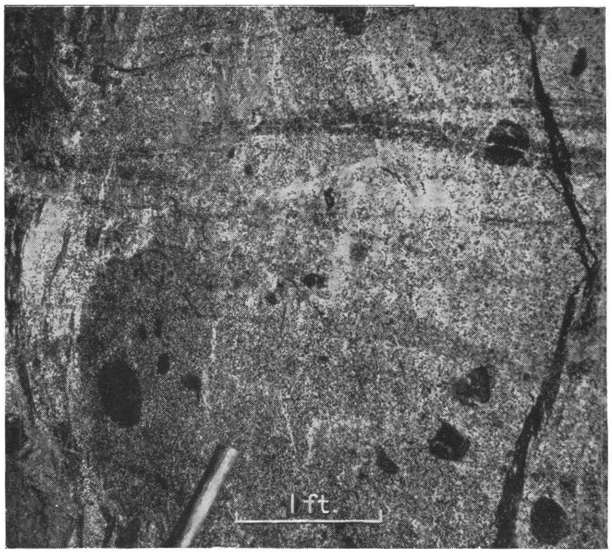
Shows sericitized plagioclase phenocrysts containing euhedral augite in groundmass of plagioclase and chloritized hornblende. One nicol.



D. QUARTZ-PORPHYRITE DIKE ROCK FROM ORLEANS MINE AREA.

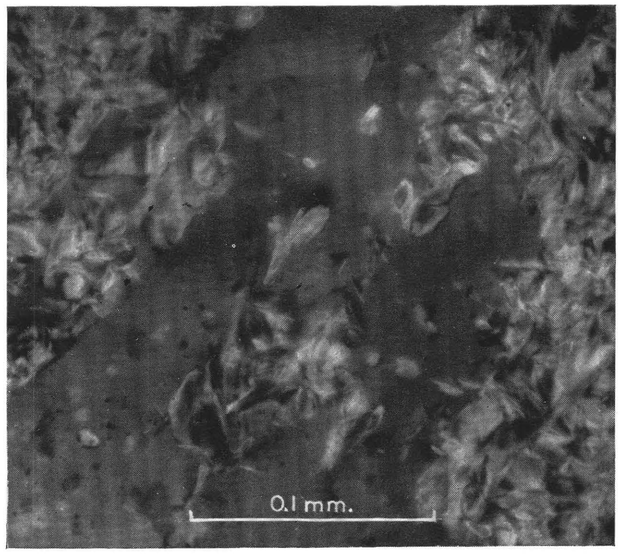
Shows chloritized augite phenocrysts (bottom) and sericitized plagioclase phenocrysts (top). One nicol.

PHOTOMICROGRAPHS OF DIABASE AND PORPHYRITE.

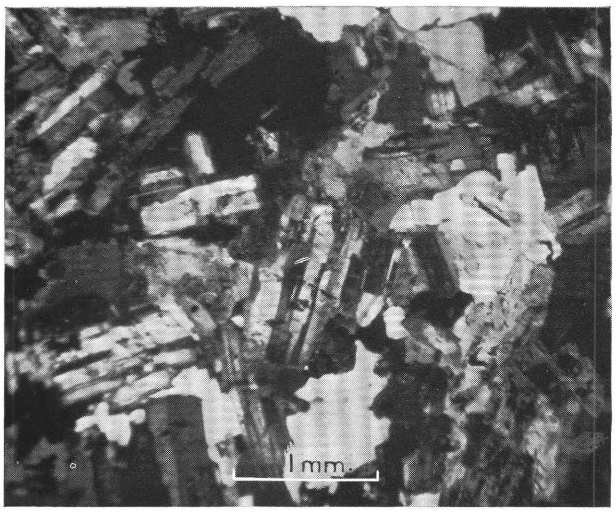


A. GRANODIORITE IN FACE OF DRIFT, 9,000-FOOT LEVEL, NORTH STAR MINE.

Shows random autoliths and carbonate alterations (dark streaks) along minor fractures.

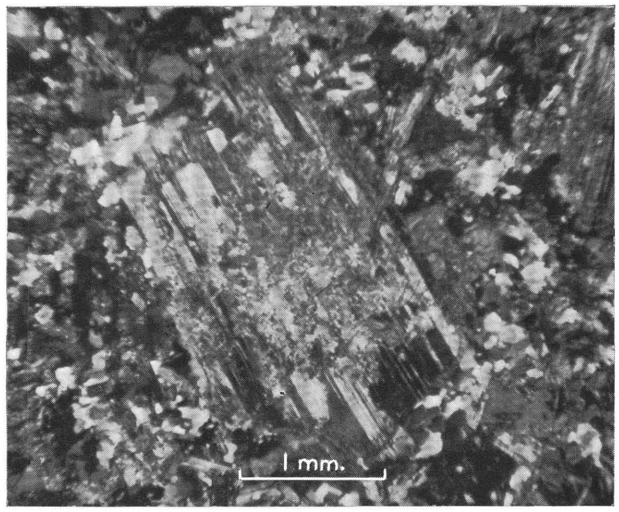


B. DETAIL OF *E* SHOWING ENCROACHMENT OF SERICITE ON QUARTZ.



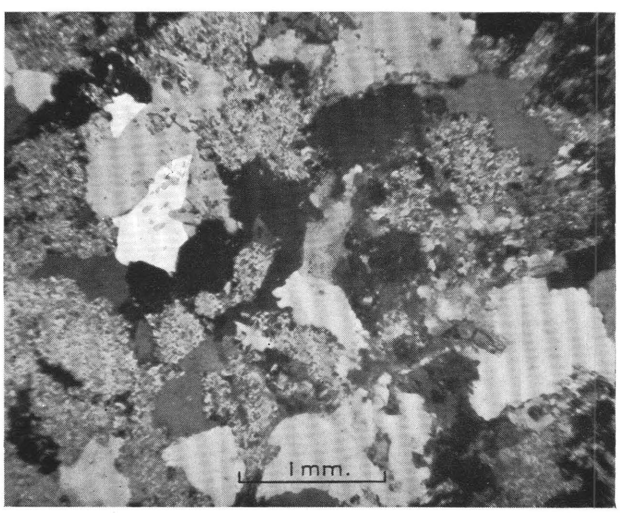
C. FRESH GRANODIORITE, 8,600-FOOT LEVEL, NORTH STAR MINE.

Crossed nicols.



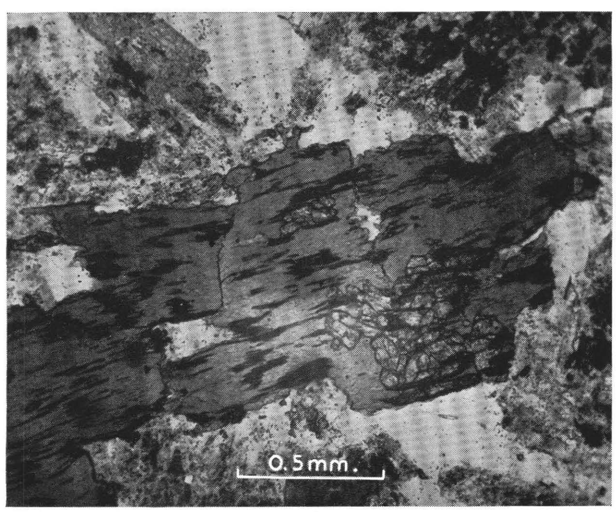
D. SERICITIZATION OF PLAGIOCLASE PHENOCRYST.

From an autolith in the face shown in *A*.



E. SERICITIZED GRANODIORITE, 8,200-FOOT LEVEL, NORTH STAR MINE.

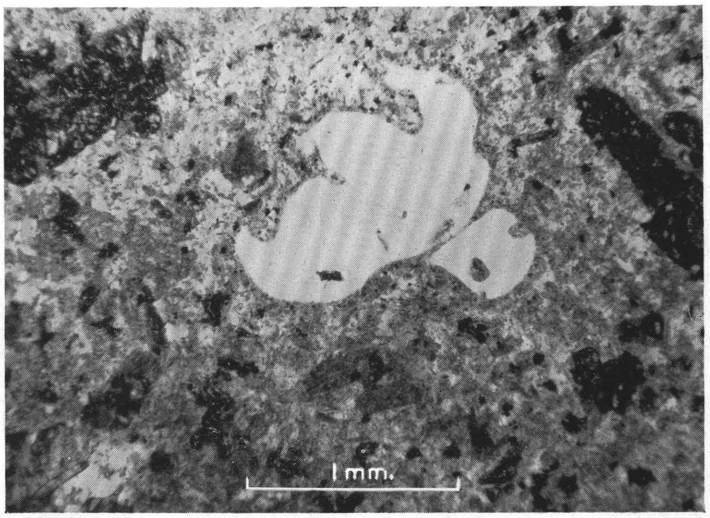
Of the original minerals only the quartz remains. Crossed nicols.



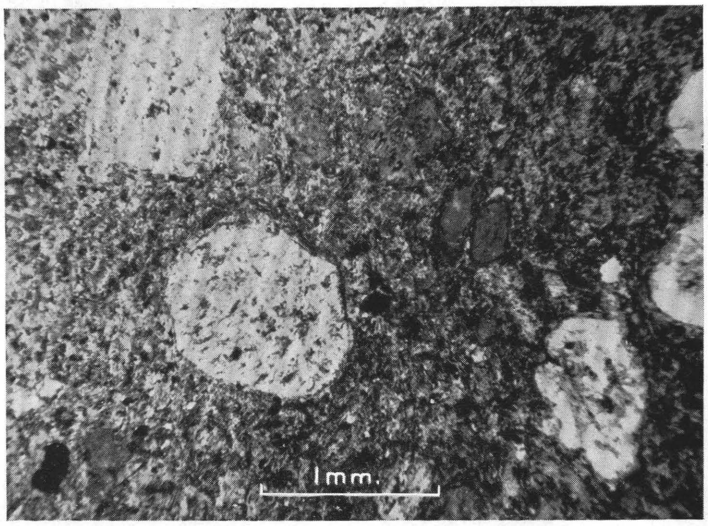
F. CHLORITIZATION OF HORNBLENDE.

From granodiorite in the face shown in *A*.

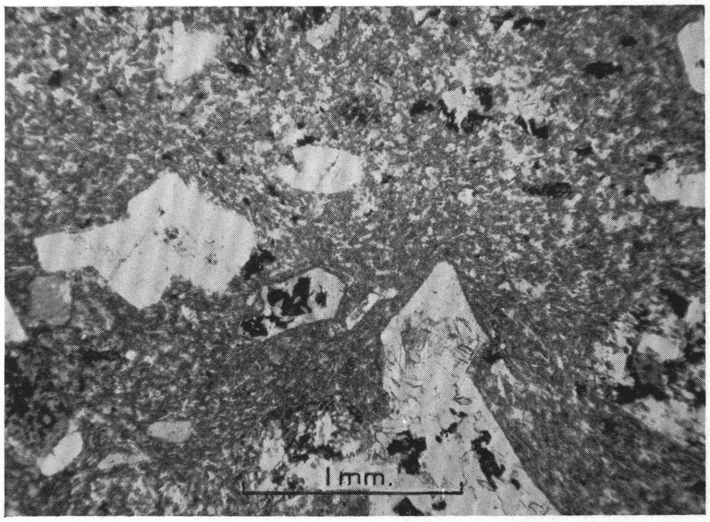
PHOTOMICROGRAPHS OF GRANODIORITE.



A. AUGITE PORPHYRITE DIKE SHOWING CORRODED QUARTZ GRAIN AND AUGITE PHENOCRYSTS.
North Star mine, 7,850-foot level. One nicol.



B. PLAGIOCLASE PORPHYRITE DIKE.
North Star mine, 9,000-foot level. Crossed nicols.



C. ANDESINE-AUGITE LAMPROPHYRE DIKE.
Empire mine, 4,200-foot level crosscut. One nicol.

PHOTOMICROGRAPHS OF POSTGRANODIORITE DIKE ROCKS OF INTERMEDIATE TO BASIC COMPOSITION.

Augite syenite.—East of Grass Valley railroad station Lindgren mapped a small area of augite syenite which he described as follows:[27]

Grayish-green medium-grained rock of diabasic appearance, usually containing scattered grains of pyrrhotite. The rock * * * consists, as seen in thin section, of lath-shaped plagioclase crystals, much clouded and filled with micaceous products, and augite as short stout crystals or filled triangular interstices between the feldspar laths. Cementing all these constitutents is a fresher and clearer feldspar without twin lamellae, which evidently is orthoclase. Small amounts of uralite and chlorite are present, while most of the titanic iron ores are converted to leucoxene. A partial analysis of this rock by Dr. H. N. Stokes gave:

	Percent
SiO_2	51. 47
CaO	7. 72
K_2O	3. 76
Na_2O	2. 92

It is not, however, probable that it is a geologically independent body, for its affiliations are clearly with the Maryland diabase area, and it is probably only a facies of that rock.

A specimen of much-weathered rock collected from the north side of the railroad in this area in 1930 proved upon microscopic study to be an albitized diabase. It is possible that the area of augite syenite may be smaller than mapped.

On the block diagrams of the Empire (pl. 35) and Pennsylvania (pl. 32) mines augite syenite, diabase, and porphyrite are indicated by the same pattern.

Amphibolite schist.—An area of amphibolite schist beginning south of the Maryland mine extends eastward beyond the border of the quadrangle. It is a dark-green to greenish-gray schistose rock, locally containing brecciated fragments of porphyrite and siliceous argillite. The schistosity is variable, and the rock shows gradations from almost unmetamorphosed porphyrite and porphyritic diabase to a strongly fissile chloritic amphibolite schist. The more strongly metamorphosed porphyrite breccias have a groundmass of chlorite, sericite, epidote, carbonates, and secondary hornblende.

The amphibolite schists in the Grass Valley area appear to be dynamometamorphic products of diabase and augite porphyrites. To the east, beyond the limits of the areas shown on the special maps, Lindgren[28] found complete transition between gabbro and amphibolite schists and suggested that diabase, porphyrite, diorite, gabbro, and even pyroxenite may be parent rocks from which the amphibolite schists are formed. He described the metamorphism of these rocks as follows:[29]

The first stage in the metamorphism consists in the uralitization of the abundant augite (and rarer hornblende) in the primary rocks; at the same time the ends of the crystals feather out in ragged and divergent aggregates of light-green hornblende, and needles of the latter scatter through the feldspars. It is not necessary, however, that this process should be completed before the alteration proper begins. The latter consists in the forming of clear, allotriomorphic granular aggregates of generally unstriated feldspars, quartz, epidote, with abundant newly formed green, frequently idiomorphic hornblende and dark-brown biotite. * * * Besides these minerals, magnetite, pyrite, and pyrrhotite are formed and contained, equivalent to the other components, in the secondary allotriomorphic mass. This new-formed mosaic encroaches gradually on the original minerals; the remaining feldspars appear as remnants, clouded by muscovitic minerals and epidote. The eventual result is the conversion of rock into an even-grained, clear and fresh mosaic, an aggregate of secondary minerals.

The first stage has been experienced to some degree by many diabasic and porphyritic rocks of the area, without, however, producing sufficient change to obscure their original character. The second stage, resulting in the amphibolite schists, appears to be the result of dynamometamorphic forces that induced schistosity to a greater or lesser degree.

Although Lindgren, in the northern Sierra, has traced the metamorphic transition of diabase and porphyrites of probable Mariposa age into amphibolite schists and so regards the age of the schists to be Mariposa or later, Knopf[30] has observed that the amphibolite schists of the Mother Lode "are interbedded with Calaveras black slates or phyllites and even grade into them as the result of original admixture of tuff and sediment." As both views are statements of observed fact, the age of the amphibolite schists of the Sierra Nevada must range, at least, between Mississippian and late Jurassic or early Cretaceous. It is highly probable that some were formed in the late Paleozoic orogeny and others in the Cordilleran revolution.

SERPENTINE, GABBRO, AND DIORITE

Serpentine, gabbro, and diorite are widespread in the Sierra Nevada. Although some are known to intrude Mariposa sedimentary rocks and are themselves intruded by granodiorite, some of the serpentines associated with the Calaveras formation and the highly schistose diorites may be much older.

In the Grass Valley area no direct evidence of the age of these rocks was obtained. The outcrop pattern suggests that the serpentine is older than the gabbro and diorite, as would be inferred from generally accepted ideas of reaction series in igneous rocks, but definite intersection relations that might serve to date the rock types were not found.

Serpentine.—Serpentine, which crops out over a large area in the northern part of the quadrangle, appears to have been formed from such highly ferromagnesian rocks as peridotites, pyroxenites, or even gabbros. It is a grayish-green to black rock cut by narrow veins of chrysotile and breaking in small rhombs here and there. Upon weathering it yields a

[27] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), pp. 68-69.

[28] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Colfax folio (no. 66), p. 4, 1900.

[29] Lindgren, Waldemar, The gold quartz veins of Nevada City and Grass Valley districts, Calif.: U. S. Geol. Survey 17th Ann. Rept., pt. 2, p. 76, 1896.

[30] Knopf, Adolph, op. cit. (Prof. Paper 157), p. 12.

soil that supports only a sparse and scrubby vegetation with a few digger pines.

The principal serpentine area lies northeast of Grass Valley and north of the south fork of Wolf Creek, extending from the St. John mine to the eastern edge of the quadrangle. On its border is the Idaho-Maryland mine. There are also two smaller serpentine areas northeast of Grass Valley, one south of the Coe mine and the other at the Crown Point mine. The larger serpentine mass has been cut by the crosscut on the 4,200-foot level of the Empire mine.

Under the microscope interlocking foils of antigorite are seen to make up the greater part of the rock. In some sections these foils have a mesh structure suggesting that the antigorite was derived from olivine. Bastite plates whose pyroxene cleavage is outlined by magnetite grains are present in some sections. A thin section of serpentine from the dump of the long-abandoned Coe mine showed bastite plates surrounded by antigorite and a few areas of clear serpentine in which a single basal cleavage is outlined by the included magnetite. This structure suggests that chlorite may have been an alteration product intermediate between olivine or pyroxene and serpentine.

Magnetite is an abundant constituent of the serpentine, and chromite, ilmenite and pyrite are accessory minerals. Actinolite, mariposite, chlorite, and undetermined carbonates are common alteration products.

The serpentine appears to bear some genetic relation to the gabbros that occur with it. It is probable that they were contemporaneous, but there is little direct evidence to bear out this assumption. In the Alleghany district the serpentine is marginal to the gabbro, and Ferguson [31] believes both rocks to be parts of the same intrusion.

That some porphyrites might have been converted to serpentine was recognized by Lindgren [32] in his study of the St. John mine.

Much of the serpentine in the district has been extensively replaced by carbonates. This is in accordance with the observations of Ferguson [33] at Alleghany and of Knopf [34] on the Mother Lode and indicates that at Grass Valley, too, serpentinization preceded ore deposition.

Gabbro.—Gabbro in association with serpentine and diorite is exposed in a few small areas in the northeast quarter of the quadrangle, and part of a larger mass lying west of the Calaveras formation occupies the southwest corner of the quadrangle.

In outcrops the rock is much weathered. It is white to gray and coarsely crystalline. In thin section it is seen to be composed of a light-colored pyroxene, probably diallage, which is almost completely converted into uralitic hornblende; and plagioclase, between bytownite and anorthite in composition ($n=1.578$), whose original character is badly masked by such alteration products as sericite, carbonates, and clay minerals. Some ilmenite and a little magnetite are the accessory minerals. In the Maryland area some of the original gabbro has been converted by regional metamorphism into a light-colored actionolite schist.

Because of the weathered condition of the exposed gabbro, unsatisfactory outcrops, and lack of exposures of fresh rock in mine workings, little information concerning its intrusive relations is at hand. The association of gabbro with diorite and serpentine suggests a common source for all three.

Diorite.—In several areas in the northeast quarter of the quadrangle diorite occurs in association with gabbro and serpentine. The rock is dark green with coarse granitic texture. It is composed of hornblende, labradorite ($Ab_{47}An_{53}$), and minor amounts of quartz, orthoclase, and magnetite. A similar rock in the adjoining Nevada City quadrangle contains small amounts of pyroxene and biotite.[35]

The diorite at Grass Valley is much altered. The hornblende has been changed to uralite and chlorite, and the plagioclase feldspar to sericite, carbonates, and clay minerals. In places secondary pyrrhotite has developed.

There is some textural variation in the diorite, and its contacts with the gabbro appear to be transitional. Lindgren [36] has pointed out that in the diorites of the Nevada City area the amount of calcium is greater than the sum of sodium and potassium whereas in the granodiorites the amount of calcium is less than the sum of sodium and potassium.

GRANODIORITE

The granodiorite at Grass Valley is more uniform in appearance and composition than any other rock in the area and is readily identified in the field. It is a medium- to coarse-grained gray to pinkish-gray rock, composed essentially of quartz, feldspar, hornblende, and locally biotite.

The main granodiorite body extends from the town of Grass Valley southward along Wolf Creek for a distance of 5 miles. In width it ranges from less than half a mile to almost two miles. In the Grass Valley quadrangle it is widest at the southern border, narrows to a neck 1,000 feet wide near the center and again widens at the north end.

Petrology.—The texture of the granodiorite is granular. The grains average 2 to 5 millimeters in diameter, with sparse large, rectangular crystals attaining a length of 1 centimeter. Photomicrographs of granodiorite are shown in plate 5.

The essential constituents are quartz, orthoclase, oligoclase, hornblende, and biotite. Accessory min-

[31] Ferguson, H. G., and Gannett, R. W., Gold quartz veins of the Alleghany district, California: U. S. Geol. Survey Prof. Paper 172, p. 13, 1932.

[32] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 222.

[33] Ferguson, H. G., and Gannett, R. W., op. cit., p. 13.

[34] Knopf, Adolph, The Mother Lode system of California: U. S. Geol. Survey Prof. Paper 157, p. 20, 1929.

[35] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 50.

[36] Idem., p. 48.

erals are apatite, zircon, titanite, and magnetite. Secondary constituents are sericite, carbonates, chlorite, pyrite, clay minerals, and locally epidote.

Under the microscope the plagioclase is the most conspicuous mineral. It occurs in rather well-formed laths showing multiple twinning and pronounced zonal structure. The greater part of the plagioclase is oligoclase with the approximate composition $Ab_{70}An_{30}$. In some crystals there is a more calcic core with the refractive index of andesine (n=1.555), and some crystals show an outer untwinned zone of albite. In plain light the plagioclase is clouded with sericite, carbonates, and clay minerals.

Orthoclase and quartz fill the interstices between laths of plagioclase and hornblende. The orthoclase is somewhat less altered than the plagioclase, but it is not clear. Rarely the quartz and orthoclase show micropegmatitic intergrowths, and a little microperthite was observed. The quartz contains spherulites and vacuoles, the latter, resolved with difficulty under a magnification of 500, sometimes showing gas bubbles occluded in liquid. These vacuoles rarely are zonally arranged.

None of the granodiorite specimens examined were absolutely fresh, but all showed some alteration of the feldspars and the hornblende. The character of the alteration process is discussed in the section on rock alteration (pp. 51–54).

The subjoined analyses of granodiorite are quoted from Lindgren's report.[37] The norms were computed by Washington [38] and the modes by Lindgren.

Analyses of the granodiorite of Grass Valley and Nevada City, Calif.

[W. F. Hillebrand, analyst]

Analyses			Mineral composition				
	1	2		1		2	
				Norm	Mode	Norm	Mode
SiO_2	63. 85	66. 65	Quartz	19. 44	20. 8	23. 34	22
Al_2O_3	15. 84	16. 15	Orthoclase	18. 35	18	16. 12	15
Fe_2O_3	1. 91	1. 52	Albite	27. 77	[1] 28	28. 82	29
FeO	2. 75	2. 36	Anorthite	19. 18	[1] 12. 1	21. 41	15
MgO	2. 07	1. 74	Corundum	-----	-----	. 71	------
CaO	4. 76	4. 53	Diopside	2. 94	-----	------	------
Na_2O	3. 29	3. 40	Hypersthene	6. 54	-----	7. 04	------
K_2O	3. 08	2. 65	Hornblende	-----	[2] 16. 6	------	[3] 16
H_2O-	. 28	. 18	Magnetite	2. 78	1. 5	2. 09	1. 50
H_2O	1. 65	. 72	Ilmenite	1. 06	-----	. 76	------
TiO_2	. 58	. 38	Titanite	-----	1. 4	------	1
P_2O_5	. 13	. 10	Apatite	. 34	. 3	. 34	. 24
MnO	. 07	. 10					
BaO	. 06	. 07		98. 40	98. 7	100. 63	99. 74
SrO	Trace	Trace					
Li_2O	Trace	Trace					
FeS_2	. 04	. 02					
	100. 36	100. 57					

[1] Ab_7An_3, 40.1 percent.
[2] Hornblende having the percentage composition: SiO_2 40.3, Al_2O_3 15.7, Fe_2O_3 and FeO 19.3, CaO 12.1, MgO 12.6.
[3] Hornblende and biotite.

1. Granodiorite from Grass Valley. Fairly fresh rock from Kate Hayes Hill. Lindgren, Waldemar, op. cit., pp. 42–43.
2. Granodiorite from Nevada City. Idem, p. 38.

[37] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), pp. 38, 42–43.

[38] Washington, H. S., Chemical analyses of igneous rocks published from 1884 to 1913, inclusive, with a critical discussion of the character and use of analyses: U. S. Geol. Survey Prof. Paper 99, pp. 259, 361, 1917.

No estimate of secondary minerals was made at the time of the analysis (1895), and as samples of the analyzed specimens were not preserved, it is impossible to determine the modal values of sericite, carbonate, and chlorite.

The following table shows (a) the average mineral composition, estimated by the Rosiwal method, of the least-altered granodiorite obtained in the field season of 1930–31 and (b) the probable composition of the unaltered rock from which it was derived.

Average composition of freshest and unaltered granodiorite

	a	b
Quartz	20	20
Orthoclase	14	15
Plagioclase	40	45
Sericite	5	0
Carbonates	1	0
Hornblende	8	14
Biotite	2	3
Chlorite	7	0
Magnetite	1. 5	1. 5
Titanite	. 5	1
Leucoxene	. 5	0
Apatite	. 5	. 5
	100. 0	100. 0

Inclusions.—Scattered throughout the granodiorite are rounded to subangular clots of darker material. These clots are variable in size, ranging from an inch or less to 1 or 2 feet in maximum diameter. Their distribution is irregular. Usually they occur with a frequency of two or three to the square yard of outcrop, but in places, particularly near the diabase contact, they are more abundant and may make up one-half of the exposed area of the granodiorite. Random inclusions on the 9,000-foot level of the North Star mine are shown in plate 5, *A*, and figure 2 is a sketch of the wall of the Empire shaft just below the diabase contact, where inclusions are abundant.

These clots have a granular structure and a grain size of approximately one-fourth to one-tenth of that of the granodiorite host. The same minerals that form the granodiorite are present in the clots—plagioclase, orthoclase, hornblende, and quartz—the principal difference being that the plagioclase and hornblende are relatively more abundant in the clots than in the host rock.

Pabst,[39] who has made detailed studies of such inclusions in the granitic rocks of the Sierra Nevada, follows Holland[40] in designating them "autoliths" in contrast with Sollas' term "xenoliths" for "picked-up fragments of foreign rocks."

In summation of his studies on the autoliths of the Sierra Nevada granitic rocks Pabst [41] makes the following observations:

[39] Pabst, Adolf, Observations on inclusions in the granitic rocks of the Sierra Nevada: California Univ., Dept. Geol. Sci., Bull., vol. 17, no. 10, p. 328, 1928.

[40] Holland, Thomas H., The charnockite series: India Geol. Survey Mem., vol. 28, p. 217.

[41] Pabst, Adolf, op cit., p. 368.

1. The autoliths are composed of the same minerals as the enclosing granitic rocks.
2. Chemically and texturally the autoliths have the characteristics of igneous rocks.
3. Although they represent a concentration of what we believed to be the early crystallizing constituents of granitic rocks, their fine grain does not permit the interpretation that they are merely the products of syneusis (swimming together).
4. The autoliths show, under favorable circumstances, a flow structure conformable to that of the enclosing rocks.
5. The flattening and orientation of the autoliths in certain localities give definite evidence that they were able to undergo plastic deformation at the time of the emplacement of the enclosing rock or even later. Moreover, they were then not fully crystallized.
6. They are not restricted to any narrowly limited set of conditions as to nature of enclosing rock, relation to contact, or position in the intrusive mass.
7. The distribution of the autoliths is apparently related to magmatic movement at the time of intrusion.

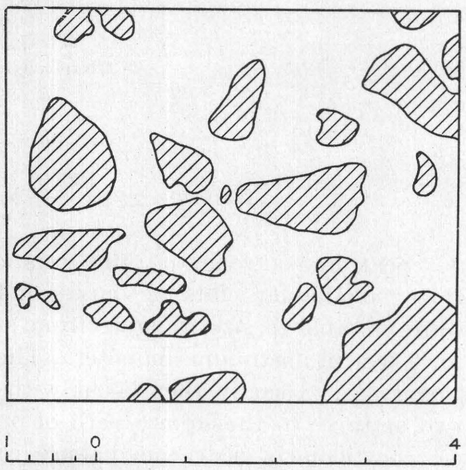


FIGURE 2.—Distribution of inclusions in the granodiorite, showing characteristic lack of orientation. Empire shaft below 1,700-foot level. Outlines traced from a photograph.

As Bowen's studies on the behavior of inclusions in magmas [42] have shown that assimilation tends to produce in inclusions the very minerals with which the magma is saturated and which it is depositing at that stage of crystallization, Pabst's first three observations cannot be considered evidence that the inclusions in the granodiorite at Grass Valley are "autoliths" and not soaked and recrystallized "xenoliths" of diabase or porphyrite formed in a manner similar to those in southern California described by Hurlbut.[43] My work at Grass Valley has shed no light on the perplexing question of the genesis of the inclusions.

In the granodiorite at Grass Valley most of the inclusions observed are equidimensional. Spindle and pancake shapes are rare, and, unlike similar clots in the granodiorite at Nevada City [44] and elsewhere in the Sierra [45] they do not have a definite orientation and so give no information as to the directions of flow in the granodiorite during its emplacement. This lack of primary orientation of inclusion, as well as of hornblende and plagioclase phenocrysts in the rock itself, strongly suggests a static condition of the granodiorite magma just prior to its solidification. Considered in connection with the strongly developed platy structure in the granodiorite at Nevada City, it further suggests that only the top of the intrusive at Grass Valley is now exposed, whereas the granodiorite at Nevada City originally extended much higher, and its present surface represents a section somewhat deeper in the mass.

Intrusive relations.—The intrusive nature of the main granodiorite body is shown wherever mine workings follow the contacts, for the walls of the intrusive, despite numerous local irregularities, flare downward. In places this downward flaring is marked, as under the re-entrant on the eastern margin of the outcrop, south of the W. Y. O. D. shaft, where the eastern wall of the intrusive has straightened at a depth of a few hundred feet. The extent of the flaring and the irregular character of the contact are shown in the cross sections and the block diagrams of the various mines.

A small dike of granodiorite, east of the town of Grass Valley and south of the Crown Point mine, is intruded into the Calaveras formation. The upper workings on the north end of Empire mine show this dike to be an offshoot of the main granodiorite mass (pl. 35). There are a few smaller dikes of granodiorite in the diabase south of the W. Y. O. D. mine, where the diabase roof is thin. Underground, granodiorite dikes in diabase are cut by the North Star 3,700 east drift, the North Star 600 level, and the Empire 1,100 north drift.

The contact of the granodiorite and diabase is remarkable for its sharpness and for the lack of fine-grained borders indicating chill or other contact phenomena. It can best be described as a truly welded contact, for hand specimens showing both rocks in typical facies are readily obtained. The contact, on the whole, is smooth, but small apophyses of granodiorite entering the diabase, such as are sketched in figure 3, are not uncommon.

Where the granodiorite is intruded in the Calaveras formation, however, the slates and sandstones show the characteristic contact-metamorphic zones described on page 8.

Age.—Urry,[46] by means of the "helium method," determined the age of a dark inclusion in granodiorite from the 9,000-foot level of the North Star mine and of the granodiorite surrounding the inclusion. Both the inclusion and the granodiorite gave an age of 110 ± 5 millions of years, which falls within the limits

[42] Bowen, N. L., The evolution of igneous rocks, pp. 197-199, 1928.

[43] Hurlbut, C. S., Jr., Dark inclusions in a tonalite of southern California: Am. Mineralogist, vol. 20, pp. 609-630, 1935.

[44] Near the Champion mine, Nevada City quadrangle, at the granodiorite-slate contact the clots are pancake-shaped or discoid and are oriented parallel with the contact.

[45] Pabst, Adolf, op. cit., fig. 2, p. 333, 1928. Cloos, Hans, Bau und Bewegung der Gebirge in Nordamerika, Skandinavien und Mitteleuropa; Fortschr. Geologie u. Paläontologie, Band 7, Heft 21, pp. 245-264, 1938. Cloos, Ernst, Der Sierra Nevada-Pluton; Geol. Rundschau, Band 22, Heft 6, pp. 379-380, 1931; Granodiorite south of Mariposa, Calif.: Am. Jour. Sci., 5th ser., vol. 23, no. 136, pp. 294-295, 1932; Der Sierra-Nevada-Pluton in Californien; Neues Jahrb., pt. 76, pp. 376-378, 1936.

[46] Urry, W. D., and Johnston, W. D., Jr., Age of the Sierra Nevada granodiorite [abstract]: Geol. Soc. America Proc. for 1935, p. 114, 1936.

tentatively assigned to the Cretaceous of 60 to 140 millions of years.[47]

As explained on page 10, recent work has cast some doubt on the absolute ages of rocks determined by the helium method, but the relative ages of the diabase, granodiorite, and later dikes are probably correct.

DARK-GRAY DIKES INTRUDING THE GRANODIORITE

Dikes of intermediate to basic composition cut the granodiorite and are exposed in the underground workings of the Empire and North Star mines. Many of these dikes closely resemble the older diabases and porphyrites in texture and mineral composition. Megascopically they are gray to greenish-black rocks, in many places porphyritic. The dikes are usually narrow, ranging from a few inches to 20 feet in width. Most of them have sharp and regular walls. A typical basic dike is sketched in figure 4.

Petrology.—Porphyrite dikes are exposed by drifts on the 7,200, 8,600 and 9,000 levels of the North Star mine and the 3,000 south level of the Empire mine and were found in granodiorite waste on the Allison Ranch mine dump. They are dark-gray porphyritic rocks. Phenocrysts of plagioclase (andesine to oligoclase) are set in a groundmass of plagioclase and augite or hornblende. Commonly the groundmass is ophitic. Several of these rocks contain corroded fragments of quartz (pl. 6, *A*), and one contains partly resorbed phenocrysts of andesine. Plate 6, *A* and *B*, shows photomicrographs of typical porphyrite dike rocks.

Augite porphyrite dikes are cut by the Chevanne shaft and the 7,200 and 7,850 drifts on the No. 1 vein, North Star mine. Under the microscope they are seen to consist of phenocrysts of augite and locally plagioclase (labradorite to andesine) set in a groundmass consisting of an ophitic intergrowth of plagioclase and augite. Like the plagioclase porphyrite dikes they also contain sparse corroded quartz grains.

The porphyritic dike rocks of both types are highly altered. The feldspars are clouded with an intergrowth of sericite and carbonates, and the augite is largely replaced by uralitic hornblende or chlorite. Much epidote has been introduced, sometimes in such quantities as to obscure the original character of the rock almost completely.

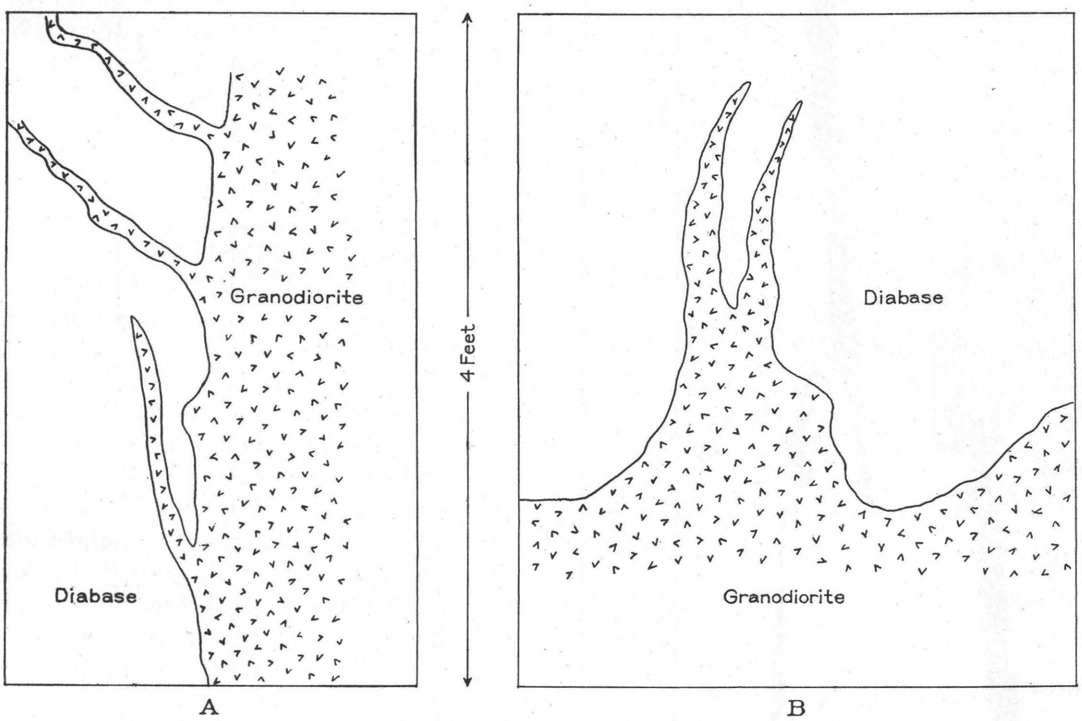


FIGURE 3.—Details of the contact between granodiorite and diabase, showing apophyses of granodiorite in diabase. A, North Star mine, 3,400 drift on A vein; B, Empire mine 3,000 level south.

In addition to the porphyrite dike rocks just described, which are similar to the older porphyrites, there are several lamprophyric dikes that do not have older equivalents.

Hornblendite dikes are exposed in the North Star mine on the 3,400 A, 4,000, and 8,600 levels, and dike rock composed almost wholly of hornblende was obtained on the dump of the Coe mine. A similar dike rock is present in the Spring Hill mine. In these dikes the hornblende constitutes 60 to 95 percent of the volume of the rock, forming well-shaped phenocrysts or an interlocking framework whose interstices are filled with an intergrowth of plagioclase (labradorite

[47] Lane, A. C., Report of the Committee on the Measurement of Geologic Time: Nat. Research Council, Div. Geology and Geography, Ann. Rept., appendix K, p. 1, Apr. 28, 1934.

to andesine) and hornblende. A little interstitial quartz, possibly of later age, was observed in one section. Magnetite is usually present in amounts as great as 5 percent by volume. The hornblende rock from the Coe mine dump has crystals 2 centimeters or less in length. The interstitial material, approximately 8 percent by volume, consists of magnetite and secondary carbonates.

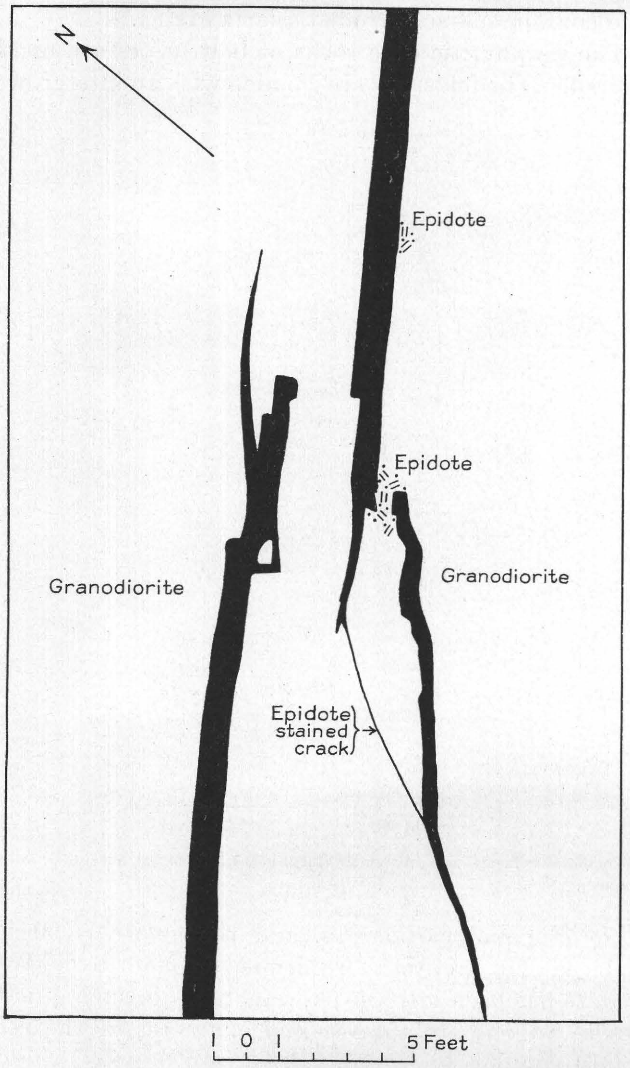


FIGURE 4.—Horizontal projection of basic dike exposed in the roof of the 8,600 station of the No. 2 winze, North Star mine.

An andesine lamprophyre or camptonite (pl. 6, *C*) is intersected by the north end of the crosscut on the 4,200-foot level of the Empire mine. It is composed of euhedral andesine and some augite phenocrysts with oligoclase rims set in a groundmass of augite and oligoclase.

A small, much-altered green dike is cut by the 5,800-foot north level of the Empire mine. It is composed of 95 percent chlorite, giving, under the microscope, a plum-colored anomalous birefringence; 4 percent epidote; and 1 percent pyrite.

A rock of some interest but uncertain habit is exposed in the west end of the 3,700-foot drift on the North Star vein. It is composed of rosettes of pink garnet 0.5 to 1 centimeter in diameter set in a groundmass of magnetite, chloritized biotite and hornblende, clouded plagioclase, and clinoenstatite ($\beta=1.67$, $\gamma-\alpha=0.011$). The rock occurs in unaltered diabase, and, from the outline of the single exposure, it appears to be a dike about 6 feet wide. From its mineral composition this rock would be classified as an eclogite, and from its form and the absence of pronounced metamorphism in the host rock it would appear to be an igneous facies rather than the more common metamorphic facies.[48]

Intrusive relations.—The extent and continuity of the dark-gray dikes are shown in the isometric projections of the various vein systems. In the North Star mine they are smaller and less continuous than the silicic dikes, but in the Empire mine the reverse is true.

In general, the dikes are parallel to the "crossings" in the granodiorite, and it is likely that they were intruded along early crossing fractures. Certainly the parallelism suggests that the directional distribution of regional stresses remained fixed from the time of the injection of the earliest dikes. The bearing of the basic dikes on the structural history of the granodiorite is described further on page 56.

The similarity in mineral composition and texture between the porphyrite dikes that cut the granodiorite and the earlier pregranodiorite porphyrite immediately suggests the existence of a single magmatic source for both rocks. It is very difficult, however, to postulate the independent existence of such a magmatic reservoir during the intrusion of the granodiorite batholith. It seems more probable that the later porphyrites were differentiates of the granodiorite magma and, with the true lamprophyres, constitute a dike series complementary to the quartz porphyries and aplites.

Age.—Urry, by means of the "helium method," determined the age of two dark-gray dike rocks that intrude granodiorite in the North Star mine.[49] A porphyrite (fig. 4) exposed on the 8,600-foot level at the no. 2 winze station, gave an age of 110 ± 7 millions of years, and a petrologically similar porphyrite dike exposed on the 9,000-foot level of the no. 3 vein gave an age of 90 ± 7 years. Like the granodiorite, the dark dikes were intruded in Cretaceous time.

As explained on page 10, recent work has cast some doubt on past determinations of absolute ages by the helium method. However, the relative ages of the dikes and the granodiorite, as determined by that method, are probably correct.

QUARTZ-RICH DIKE ROCKS

Aplite and granite porphyry.—Aplite and granite porphyry, composed mainly of quartz and orthoclase with minor amounts of sodic plagioclase (albite and oligoclase), occur in dikes cutting the granodiorite and

[48] Eskola, Pentti, On the eclogites of Norway: Vidensk Selsk. skrifter, I, Mat.-naturv. Klasse, 1921, no. 8, p. 5.

[49] Urry, W. D., and Johnston, W. D., Jr., op. cit.

earlier rocks, and underground they are most conspicuous where they intrude the dark-colored diabase. They rarely contain more than 1 percent of biotite or hornblende. They are white, light greenish gray, or pink and weather to a chalky cream color.

Lindgren [50] has divided these quartz-rich dike rocks into aplites and granite porphyries ("quartz porphyry" on his Grass Valley map). This division is based wholly on textural differences, for the aplites differ from the granite porphyries only in grain size and texture, the larger dikes, in general, being granite porphyries and the smaller dikes aplites, although a few of the smaller dikes are finely crystalline and have a feebly porphyritic habit.

The similarity in chemical composition of the aplites and granite porphyries is shown by the following partial analyses of rocks of both types.

Partial analyses of silicic dike rocks from Grass Valley and Nevada City [1]

[Analyses 1, 2, and 4 by George Steiger; 3 by H. N. Stokes]

	Aplite		Granite porphyry	
	1	2	3	4
Lindgren's Specimen No.	220 NC	159 NC	113 GV	109 GV
SiO_2	--------	77.05	75.45	--------
K_2O	5.57	5.06	4.53	4.21
Na_2O	3.43	3.43	3.53	3.20
CaO	1.06	.73	.69	.60

[1] Lindgren, Waldemar, The gold-quartz veins of Nevada City and Grass Valley, Calif.: Geol. Survey 17th Ann. Rept., pt. 2, pp. 44-46, 1896.

1. Dike 3 feet wide, 1 mile above Jones Bar, Nevada City quadrangle.
2. Branching dikes in northwest part of Nevada City, Nevada City quadrangle.
3. Large dike at Omaha mine, Grass Valley quadrangle.
4. Smaller dike 1,400 feet north of Omaha mine, Grass Valley quadrangle.

Lindgren defined aplite [51] as a term used "to designate granular to fine-granular acid rocks, chiefly consisting of alkali feldspars and quartz, and usually occurring as dikes or dikelike masses in or near the larger bodies of granitic rocks." He defined granite porphyry [52] as "holocrystalline, porphyritic dike rocks, rich in free silica and characterized by the prevalence of alkali feldspars."

As the extensive underground workings opened since Lindgren's time have exposed new dikes, many of which have textures intermediate between his two rock types, it has seemed advisable to consider all such quartz-rich dikes as gradational facies of a single rock.

Distribution.—A large dike of quartz porphyry occurs in the diabase near the granodiorite contact near the Omaha mine, and smaller dikes crop out in Wolf Creek north of the Omaha mine and are cut by the New York Hill drain tunnel.

In the North Star mine a series of quartz-rich dikes striking in the northeast quadrant extend from the 4,000 to the 1,900 level. These dikes are in part quartz porphyries and in part aplites. Aplitic dikes are cut by the west North Star vein drifts on the 3,700, 2,700, 2,300, 1,900, and 1,800 levels in the same mine. Other acidic dikes are exposed on the 6,000, 6,300, 6,600, 7,200, 7,500, 7,850, 8,200, and 8,600 levels. The intrusive relations of these dikes are shown in plates 27 and 35.

Other quartz-rich dikes, mainly aplites, are cut by the 4,200, 5,000, and 5,400 level drifts of the Empire mine.

Petrology.—The aplites have a subeuhedral to completely euhedral texture and are composed of quartz

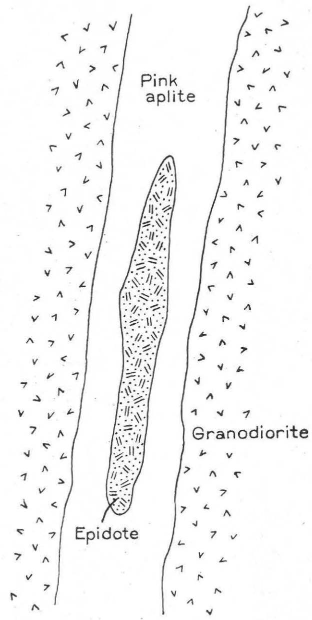


FIGURE 5.—Epidote segregation in small aplite dike, Chevanne shaft.

and orthoclase with smaller amounts of albite and oligoclase. The usual range of grain size is from 0.1 to 1 millimeter, but aphanitic varieties have grains 0.02 to 0.05 millimeter in diameter. Quartz usually constitutes one-half to two-thirds of the rock. Hornblende and biotite are locally present in small quantities, usually under 1 percent by volume. Small segregations of epidote (pistacite) are present in some of the fine-grained dikes. An example (fig. 5) is in a small pinkish aplite in the Chevanne shaft, 1.5 centimeters wide where the epidote segregation occupies the middle third of the dike. One of Mr. Knaebel's thin sections of a dike 5 centimeters wide from the 6,200-foot level of the Empire mine shows a chilled border 2 millimeters wide. The average grain diameter of the body of the dike is 0.25 millimeter, and of the chilled border 0.05 millimeter.

The groundmass of the quartz porphyries is granular, composed of approximately equal parts of quartz and orthoclase with a small amount of albite or oligoclase. The average grain size of the groundmass ranges be-

[50] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), pp. 44-45.
[51] Idem, p. 44.
[52] Idem, p. 45.

tween 0.1 and 0.5 millimeter. The phenocrysts may be orthoclase or quartz, mostly with imperfect outlines, and some of the quartz phenocrysts appear to be corroded. Micropegmatitic intergrowths of quartz and orthoclase are common in the quartz porphyries and occur, to a lesser extent, in the aplites. The intergrowths are mostly of micropegmatitic texture, but some show plumelike granophyric forms.

All the feldspars are somewhat altered. In the fresher dike rocks the feldspars are slightly clouded, but in specimens from the vicinity of veins they are more or less filled with sericite, which has attacked first the feldspar and then the quartz.

Intrusive relations.—The quartz-rich dikes cut the granodiorite and the older rocks. A single exception

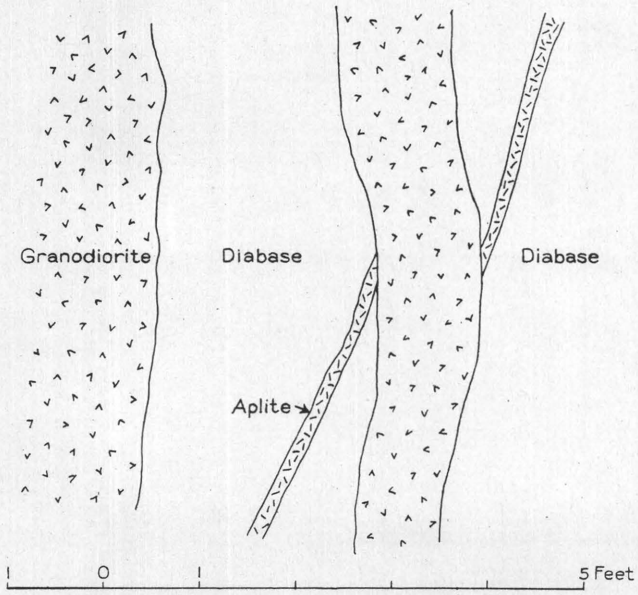


FIGURE 6.—Pregranodiorite aplite, 600-foot level, North Star mine.

to this relation was observed on the 600-foot level of the North Star mine near the granodiorite-diabase contact, where a 2-inch aplite dike is cut by a granodiorite dike 1 foot wide (fig. 6). It thus appears that although the greater part of the aplite intrusion followed the consolidation of the granodiorite, there were early aplites that antedated the last of the granodiorite intrusives. As the aplites also cut dark-colored dikes intruded into the granodiorite (fig. 39 and pl. 24), and as both granodiorite and basic dikes were faulted before the introduction of the aplite, it appears that a source of silicic magma was in existence at least from the time of latest granodioritic intrusion until the main body of granodiorite had cooled to a consistency permitting competent fracture.

Age.—The age of a single aplite from the 6,000-foot level of the North Star mine was determined by the "helium method" as 98 ± 4 millions of years.[53] In age this aplite falls between the two dark dikes that were determined as 110 ± 7 and $90 \pm ?$ millions of years old.

[53] Urry, W. D., and Johnston, W. D., Jr., op. cit., p. 114.

Aplites cutting dark dikes have been observed (pl. 24), but no dark dikes intersecting aplites.

As explained on page 10, recent work has cast some doubt on the absolute ages obtained by the helium method. It appears, however, that the relative ages of the diabase, granodiorite, and dikes, as determined by that method are correct.

TERTIARY ROCKS

In the Sierra Nevada all rocks that were laid down after the Cordilleran revolution were grouped by Lindgren in the †Superjacent series, in contrast with the older rocks of the †Bedrock series, which underwent deformation in late Jurassic or early Cretaceous time. The principal rock types of the Tertiary formations, which were included in the †Superjacent series, are rhyolite, rhyolite tuff and breccia; andesite, andesite tuff, breccia, and mud flows; and interbedded stream sands and gravels, many of which are auriferous. Pliocene basalts were erupted in many places. The rhyolitic tuffs of early Tertiary age that are present in Cement Hill and Harmony Ridge, near Nevada City, are absent in the Grass Valley quadrangle except for a small area mapped by Lindgren in the Brunswick quadrangle on the south side of Wolf Creek. As the present investigation is concerned only with the geology of the vein systems, no work has been done on the Tertiary deposits, and the brief summary here given is intended only as an explanation of Lindgren's map, which is reprinted as plate 1 of this report.

Preandesitic auriferous gravels.—Prevolcanic gravels have been mined on Alta Hill, northwest of town, and on the western edge of the andesitic capping southwest of town. The Alta channel, outlined by Lindgren's map, has been followed by several thousand feet of drifts and several shafts. It is estimated to have produced $1,000,000. The gravels under the lava capping southeast of Grass Valley were worked by drifts and hydraulic mining, but the production was not large. Lindgren [54] summarized the available knowledge of the auriferous gravels in his report published in 1911. In the Grass Valley quadrangle the production of the gravel deposits is eclipsed by the many times greater production of the gold-quartz veins.

Andesite.—Alta Hill and an area on the eastern margin of the quadrangle are covered by a deep dusty red soil containing abundant fragments of andesite as much as a foot in diameter. The andesite appears to have moved as a mud flow rather than as a molten stream, for better exposures in the Nevada City area show it to be composed of fragments of andesite embedded in a matrix of detrital andesitic material. A thin section of a large fragment found on Alta Hill showed phenocrysts of augite and plagioclase in a groundmass that was not resolved under high magnifi-

[54] Lindgren, Waldemar, Tertiary gravels of the Sierra Nevada of California: U. S. Geol. Survey Prof. Paper 73, 1911.

cation. Hand specimens of other andesite fragments showed small phenocrysts of a black amphibole, probably hornblende, in a greenish-gray groundmass.

ORE DEPOSITS

HISTORY AND PRODUCTION

Marshall is credited with the discovery of placer gold in the race of his mill at Coloma, in 1848. Placer deposits in the stream channels of the lower western slope of the Sierra Nevada were located in the gold rush of 1849, and soon the intervolcanic placer deposits or bench gravels were being actively worked.

Bayard Taylor,[55] who visited a number of gold camps in 1849, tells of the initial discovery of gold quartz veins:

At the United States Hotel I again met with Colonel Fremont and learned the particulars of the magnificent discovery which had just been made upon his ranch on the Mariposa River. It was nothing less than a vein of gold in the solid rock—the first which had been found in California. I saw some specimens which were in Colonel Fremont's possession. The stone was a reddish quartz, filled with rich veins of gold, and far surpassing the specimens brought from North Carolina and Georgia. Some stones picked up on the top of the quartz strata, without particular selection, yielded 2 ounces of gold to every 25 pounds. * * * The Sierra Nevada is pierced in every part with the priceless veins, which will produce gold for centuries after every spot of earth from base to summit shall have been turned over and washed out.

A monument erected on the site of the headframe of the old Gold Hill mine, on the outskirts of Grass Valley, bears the following inscription:

This tablet commemorates the discovery of gold-bearing quartz and the beginning of quartz mining in California. The discovery was made at Gold Hill by George Knight, October 1850. The occurrence of gold-bearing quartz was undoubtedly noted here and elsewhere about the same time, or previously, but the above discovery caused the great excitement that started the development of quartz mining into a great industry. The Gold Hill mine from 1850 to 1867 is credited with a total production of $4,000,000.

An account of early mining in Grass Valley is contained in Bean's directory [56] published in 1867.

After the discovery at Gold Hill, two Germans made the first stamp mill, in the winter of 1850. It was a crude affair with stamps made from tree trunks shod with iron. In 1851 the Gold Hill mill was completed, but not until 1857 had the stamp mill attained an efficiency that promised successful mining.

Soon after the discovery of Gold Hill, the veins of Ophir Hill, Rich Hill, and Massachusetts Hill were located. The early claims were 34 by 40 feet in size. Later mining claims of irregular shape and size grew out of the consolidation of those early claims.

By 1857 quartz mining was well established, and the Allison Ranch was, perhaps, the leading mine. The rush for the Comstock lode that began in 1859 took many miners from Grass Valley, and in the winter of 1861–62 the best mines were flooded, delaying operations until spring. For a time mining was at a standstill. In 1864 miners began to return from the Comstock, and in 1867 the Allison Ranch, Pennsylvania, Gold Hill, Peabody, Eureka-Idaho, Lone Jack, Homeward Bound, North Star, New York Hill, Massachusetts Hill, Rocky Bar, Ophir Hill, Rich Hill, Magenta, Osborne Hill, and Empire mines were in active operation, 284 stamps were falling, and 1,600 men were mining.

Starr [57] continues the history as follows:

From 1867 the mines were supposed to be "petering out," and in 1879 Grass Valley was known as a worked-out, dying camp, with but three mines in active operation, the Idaho, New York Hill, and Empire, the first in "bonanza" and the other two in "borasco." In May 1880 the New York Hill closed down, leaving the fate of the camp with the great Idaho and the struggling old Empire. To the Empire mine Grass Valley owes a debt of lasting gratitude, for in the history of that mine, more than to all other circumstances combined, is due Grass Valley's growth from a temporary mining camp to an attractive city of permanent homes.

In the history of gold mining in California the Empire stands preeminent, not alone for its wealth but for what the mine, above all others, has given in the way of example and earnest, well-applied endeavor. It is the pioneer in deep mining and the first to regard Grass Valley mining a legitimate business, controlled by the same laws and conditions as should govern a well-managed manufacturing establishment.

The North Star mine, which had been closed in 1875, was reopened in 1884 by W. B. Bourne, Jr., who sold it to J. D. Hague and associates in 1887. Between 1884 and 1897 the inclined shaft was deepened to the 2,300-foot level, and much good ore was found. Between 1890 and 1900 the North Star, Empire, Idaho-Maryland, Pennsylvania, and W. Y. O. D. were the principal mines in the district. In 1900 both the Empire and the North Star inclined shafts bottomed at 3,000 feet, the Idaho-Maryland had been sunk 2,000 feet on the dip of the vein, but the levels below 1,600 feet were no longer accessible. The bottom of the Pennsylvania mine was the 700-foot level, and that of the W. Y. O. D. the 1,200-foot level.

From the early years mine shafts have been inclined, following the vein from its outcrop downward and increasing or decreasing their slopes with the undulations of the vein. Levels were named according to their distance from the collars of the inclined shafts. Although vertical shafts a few hundred feet in depth had been sunk on several properties, the first important departure from the old custom came in 1897, when a vertical shaft designed to cut the North Star vein at the 4,000-foot level was started. The shaft reached its objective at a vertical depth of 1,630 feet in 1901. Later it was deepened to the 8,600-foot level, vertically 3,494 feet beneath the surface.

[55] Taylor, Bayard, Eldorado: Adventures in the path of empire, vol. 1, pp. 110-111, New York, 1850.

[56] Bean, E. F., History and directory of Nevada County, pp. 48-57, Nevada City, 1867.

[57] Starr, G. W. The Empire mine, past and present: Min. and Sci. Press, vol. 81, p. 120, 1900.

Before 1900 the Idaho-Maryland had been the most productive mine in the district, yielding $12,500,000 in gold and paying over $5,000,000 in dividends between 1868 and 1900. As production of the Empire and North Star mines rapidly increased in the early years of the new century that of the Idaho-Maryland dwindled, and the mine was closed in 1901.

From 1900 to 1925 the North Star mine, under the direction of James D. Hague and A. D. Foote, and the Empire mine, under the direction of George W. Starr, produced most of the gold mined in Nevada County. The North Star reached its peak in 1909, when $1,245,077 was produced, and the Empire's best year was 1917, when it yielded $1,848,623. From the peak years tonnage was maintained while the grade of ore declined, and in 1928 each mine produced a little over $800,000, but this did not meet mining costs. Upon recommendation of Fred Searls, Jr., both mines were purchased by the Newmont Mining Corporation and have since been operated as the Empire-Star Mines Co., Inc., under the local management of Frederick W. Nobs, who was long associated with Mr. Starr at the Empire. In 1931 the mines were physically united when a manway connected the 4,600-foot level of the Empire and the 5,300-foot level of the North Star.

In 1919 the Idaho-Maryland was reopened by the Metals Exploration Co., financed by H. P. Whitney, but work was abandoned in 1925. The property was then taken over by E. L. Oliver, Errol MacBoyle, and associates, who have again brought it into successful production.

The history of Grass Valley mining is essentially the history of the three great mines—the North Star, the Empire, and the Idaho-Maryland. Many others have been operated from time to time, some of them with considerable success, but none have attained the record of continuous production over a long span of years. Brief histories of individual mines are contained in the section on mine descriptions.

F. M. Miller, a mining engineer long resident in Grass Valley, has estimated the

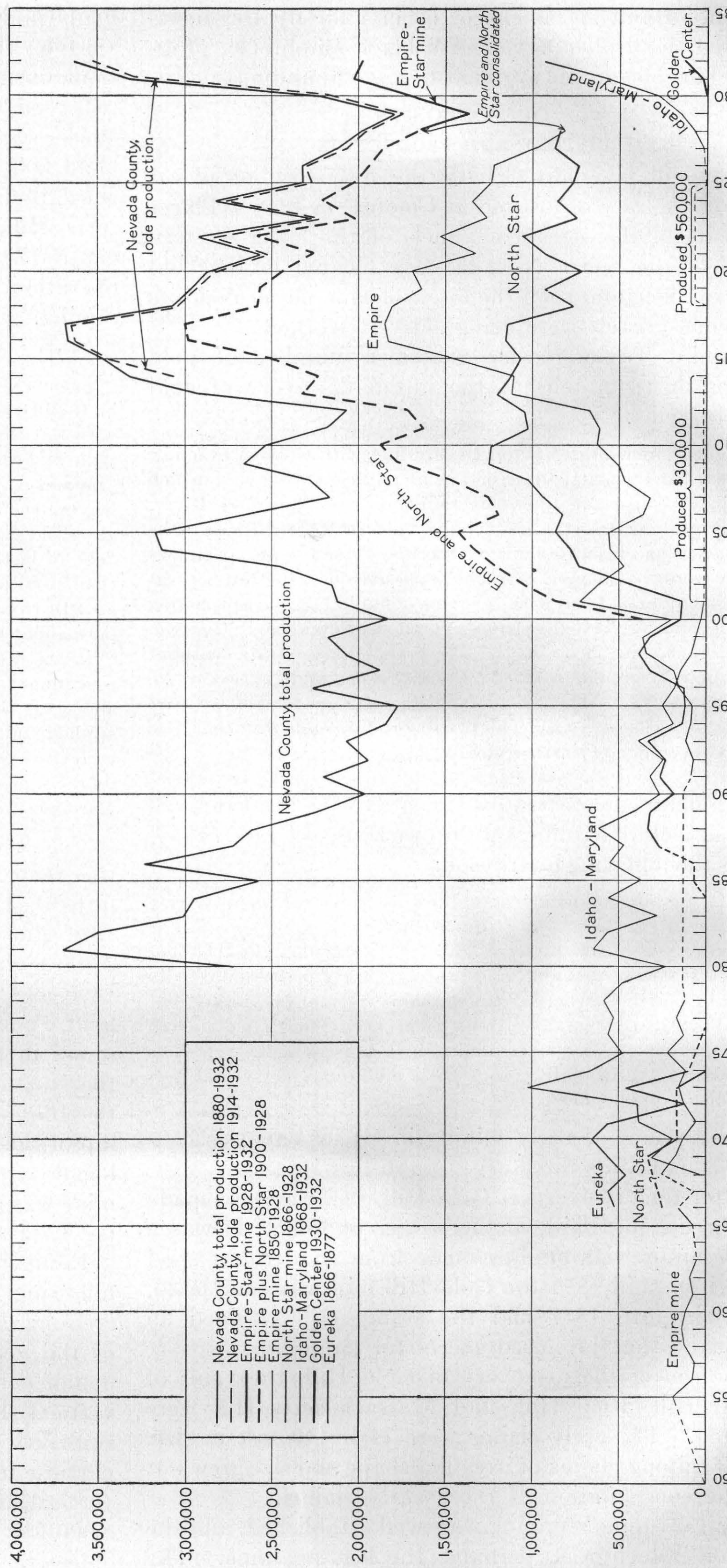


FIGURE 7.—Gold production of Nevada County, Calif., 1880-1932, and of the principal Grass Valley mines.

total production of the lode mines of the district from 1850 to 1934 to be $151,750,000. Details of his estimate are given in the following table, taken from a blueprint map of the mining claims of the western portion of Nevada County, issued by him in 1934.

Total production of the quartz mines of the Grass Valley district

[Estimated by F. M. Miller, 1934]

Mines	Inclined depth (feet)	Production
Empire-Pennsylvania	1, 400–7, 000	$51, 500, 000
Orleans-Sultana-Osborne Hill	800–1, 250	7, 500, 000
Bullion-Ben Franklin-Alaska	400–1, 500	3, 500, 000
Omaha-Allison Ranch-Norumbagua	1, 000–1, 500	7, 500, 000
North Star-Massachusetts Hill-Gold Hill	1, 200–9, 200	46, 000, 000
Golden Center-North areas	400–1, 300	2, 250, 000
Eureka-Idaho-Maryland	800–2, 300	28, 500, 000
Spring Hill-Union Hill-Brunswick	900–1, 200	5, 000, 000
	------------	151, 750, 000

The total known production of the North Star and Empire mines through 1932 is approximately $75,000,000, and the Idaho-Maryland mine has produced $15,500,000. Yearly production figures for individual mines, where available, are given in the section on mine descriptions. In figure 7 the yearly gold production for Nevada County, which includes both the Nevada City and Grass Valley districts, is represented graphically, as well as the yearly production of the principal active mines of the Grass Valley district.

MINING CONDITIONS AT DEPTH

GEOTHERMAL GRADIENT

In the course of underground mapping at the Empire-Star mine, temperature measurements were taken on 21 different levels. These temperature observations were made in air or in standing water, usually on the drift face and always outside the path of air circulation. From three to six observations were made on each level, and the temperature given in the following table is an average for the level. The value for the North Star 9,000 level is a rock temperature, obtained by averaging the readings of three maximum thermometers, which had remained for 24 hours in a bore hole 4 feet deep near an advancing face.

The temperature data were adjusted by a method adopted several years ago by C. E. Van Orstrand, which consists in adjusting a series of straight lines from the shallowest depth at which a temperature test is made to a number of gradually increasing depths as shown in the last column of the following table:

Temperature gradient at the Empire-Star mine, Grass Valley, Nevada County, Calif.[1]

Location of observation		Depth [2]		Observed temperatures		0–980 feet		0–3400 feet		Constants [3]
Mine	Level	Meters	Feet	Centigrade	Fahrenheit	Computed temperature	Observed minus computed	Computed temperature	Observed minus computed	
Empire	1, 100	0. 0	0	12. 4	54. 4	54. 2	+0. 2	54. 6	−0. 2	0–980 feet
Pennsylvania	1, 000	45. 7	150	12. 9	55. 3	55. 1	+. 2	55. 4	−. 1	$a =$ 54. 17
New York Hill	600	94. 5	310	13. 1	55. 6	56. 0	−. 4	56. 3	−. 7	$b =$ 0. 00593
North Star	1, 900	114. 3	375	13. 6	56. 4	56. 3	+. 1	56. 6	−. 2	$1/b =$ 168. 6
Pennsylvania	1, 400	128. 0	420	13. 5	56. 3	56. 7	−. 4	56. 8	−. 5	$r = \pm 0.18$
Pennsylvania	1, 700	192. 0	630	14. 3	57. 7	57. 9	−. 2	57. 9	−. 2	$r_a = \pm 0.11$
Empire	2, 700	207. 3	680	14. 7	58. 5	58. 2	+. 3	58. 2	+. 3	$r_b = \pm 0.00007$
Pennsylvania	2, 100	256. 0	840	15. 1	59. 1	59. 1	0	59. 1	0	0–2,100 feet
Empire	3, 000	257. 5	845	15. 3	59. 5	59. 2	+. 3	59. 1	+. 4	$a =$ 54. 32
Pennsylvania	2, 400	292. 6	960	15. 5	59. 9	59. 9	0	59. 7	+. 2	$b =$ 0. 00569
Empire	3, 400	298. 7	980	15. 5	59. 9	60. 0	−. 1	59. 8	+. 1	$1/b =$ 175. 8
Empire	3, 800	377. 9	1, 240	16. 6	61. 8	61. 5	+. 3	61. 2	+. 6	$r = \pm 0.21$
Empire	4, 200	432. 8	1, 420	17. 2	62. 9	62. 6	+. 3	62. 1	+. 8	$r_a = \pm 0.10$
Empire	4, 600	496. 8	1, 630	17. 4	63. 3	63. 8	−. 5	63. 2	+. 1	$r_b = \pm 0.00009$
Empire	5, 000	559. 3	1, 835	17. 9	64. 3	65. 1	−. 8	64. 3	0	0–3,120 feet
Empire	5, 400	640. 1	2, 100	19. 0	66. 2	66. 6	−. 4	65. 7	+. 5	$a =$ 54. 55
Empire	5, 800	719. 3	2, 360	19. 5	67. 1	68. 2	−1. 1	67. 1	0	$b =$ 0. 00537
Empire	6, 200	795. 5	2, 610	20. 2	68. 3	69. 7	−1. 4	68. 4	−. 1	$1/b =$ 186. 1
Empire	7, 000	951. 0	3, 120	21. 6	70. 8	72. 7	−1. 9	71. 1	−. 3	$r = \pm 0.25$
North Star	8, 700	1, 005. 8	3, 300	22. 0	71. 6	73. 7	−2. 1	72. 0	−. 4	$r_a = \pm 0.10$
North Star	9, 000	1, 036. 3	3, 400	22. 4	72. 3	74. 3	−2. 0	72. 5	−. 2	$r_b = \pm 0.00007$
										0–3,400 feet
										$a =$ 54. 63
										$b =$ 0. 00527
										$1/b =$ 189. 8
										$r = \pm 0.26$
										$r_a = \pm 0.09$
										$r_b = \pm 0.00005$

[1] Observations made in 1930–31. Most of the observations were made in air or standing water outside of the path of air circulation.
[2] Depth below Empire 1,100 level, altitude 2,200 feet, which is taken as the temperature datum. This is about 300 feet below the surface of the ground.
[3] Constants have been determined by the method of least squares from the equation $y=a+bx$.

The equation to be adjusted each time is—

$$y=a+bx$$

in which

y=temperature at depth x.
a=computed annual mean temperature just beneath the surface of the earth.
b=gradient in degrees Fahrenheit per foot.
$1/b$=reciprocal gradient in feet per degree Fahrenheit.
r=probable error of observation y, weight unity.
r_a, r_b=probable error of a and b.

All of the computations were carried out by H. Cecil Spicer, junior geophysicist in the physical laboratory of the Geological Survey.

The depth-temperature curve (see fig. 8) is slightly concave toward the depth axis. This is clearly shown in the following values of the reciprocal gradients taken from the table:

From 300 to 1,280 feet, 1° F. for every 168.6 feet.
From 300 to 2,400 feet, 1° F. for every 175.8 feet.
From 300 to 3,420 feet, 1° F. for every 186.1 feet.
From 300 to 3,700 feet, 1° F. for every 189.8 feet.

As the rock temperature on the 9,000-foot level of the North Star mine (vertical depth 3,400 feet) is only

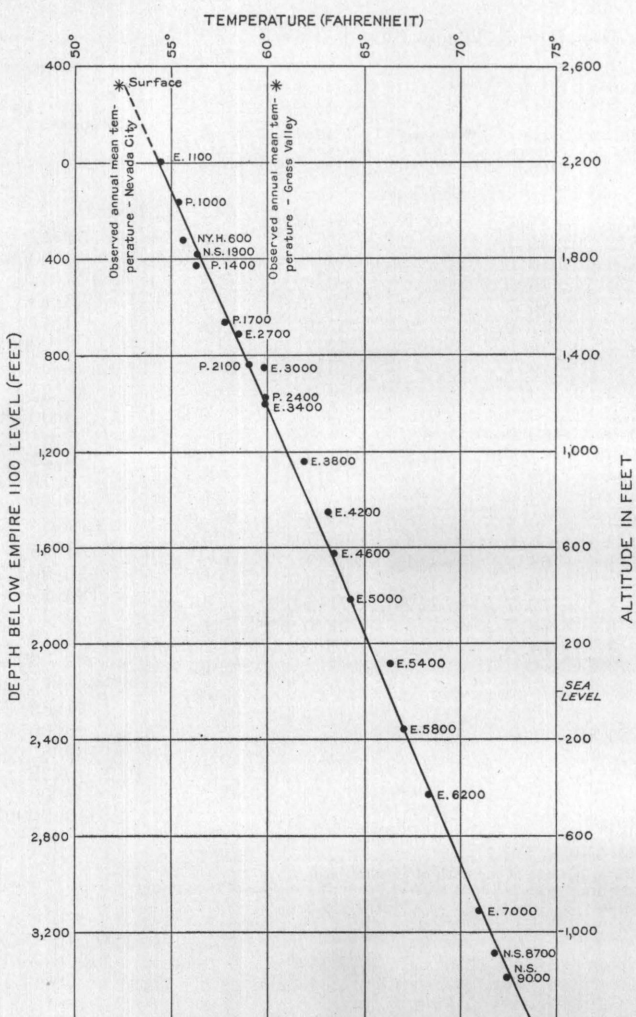


FIGURE 8.—Depth-temperature curve of the Empire-Star mine, Grass Valley, Calif.

72.3° F., underground temperature offers no hindrance to mining operations.

In figure 8 the observed surface mean annual temperatures at Grass Valley and Nevada City are shown. The mean annual temperature for Nevada City,[58] 6 miles north of the mine, obtained over a period of 39 years, is 52.6°, agreeing with the calculated subsurface temperature within 1°. The mean annual temperature near the mine at Grass Valley,[58] however, taken over a period of 22 years is 60.3° or 7° higher than the calculated subsurface temperature. This excess of observed over calculated temperature is probably due to the location of the Weather Bureau thermometer shelter at Grass Valley, for it is in the partly enclosed yard of the Empire mine near the collar of the shaft. Warm air pouring out of the shaft during the winter may well account for the excessive observed mean annual temperature.

Temperatures of deep mines in other districts are given in the following table:

Temperature of deep mines

	Observed temperature at 100 feet (° F.)	Greatest depth (feet)	Observed temperature at greatest depth (° F.)	Gradient per degree F. (feet)
Grass Valley, Calif.	[1] 54.4	3,700	72.3	189.8
Mother Lode, Calif.[2]		4,200	86.0	150.0
Calumet, Mich.[3]	44.6	5,367	89.7	117.4
Do.[4]		5,679	95.3	108.5
Minas Geraes, Brazil [5]		6,140	115.7	124.8
Johannesburg, South Africa [3]		7,032	97.0	202.1
Porcupine district, Ontario [6]		3,892		201.6
Kirkland Lake district, Ontario [6]		4,905		137.6
Frood mine, Sudbury, Ontario [6]		3,100		155.2
Franklin Furnace, N. J.[7]		2,500		170.8

[1] At 300 ± feet.
[2] Knopf, Adolph, The Mother Lode system of California: Geol. Survey Prof. Paper 157, pp. 22–23, 1929. An alternative value for $1/b$ of 160±5 for the Mother Lode has been computed from Knopf's data. See Johnston, W. D., Jr., Geothermal gradient of the Mother Lode belt, Calif.: Washington Acad. Sci. Jour., vol. 22, pp. 390–393, 1932.
[3] Van Orstrand, C. E., On the nature of isogeothermal surfaces: Am. Jour. Sci., 5th ser., vol. 15, pp. 509–511, 1928.
[4] Ingersoll, L. A., Geothermal gradient determinations in the Lake Superior copper mines [abstract]: Phys. Rev., vol. 39, no. 5, pp. 869–870, 1932.
[5] Van Orstrand, C. E., Normal geothermal gradient in the United States: Am. Assoc. Petroleum Geologists Bull., vol. 19, p. 109, 1935.
[6] Cleland, R. H., Rock temperatures and some ventilation conditions in the mines of northern Ontario: Canadian Min. Met. Bull. 256, pp. 379–407, 1933. Porcupine district is an average gradient for 3 mines, Kirkland Lake district for 5 mines.
[7] Van Orstrand, C. E., op. cit., p. 80.

As pointed out by Lindgren,[59] many mines in the California gold belt have remarkably low temperatures considering their depth. Recent observations in deep-mining districts throughout the world have shown that a gradient of 150 to 200 feet per degree Fahrenheit is not uncommon.

The low gradients of mines in pre-Tertiary igneous rocks contrast sharply with the higher gradients generally met in sedimentary rocks.[60]

[58] U. S. Weather Bureau, Climatological Data, vol. 17, no. 13, pp. 88–99, 1930.
[59] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 171.
[60] Van Orstrand, C. E., Normal geothermal gradients in the United States: Am. Assoc. Petroleum Geologists Bull., vol. 19, pp. 78–115, 1935; Temperature gradients: Problems of petroleum geology (Sidney Powers memorial volume), pp. 989–1021, Am. Assoc. Petroleum Geologists, 1934.

SUBSIDENCE AND ROCK BURSTS

Mine workings in such competent rocks as granodiorite and diabase stand for many years before caving. This is, of course, true only for excavations of relatively small section, such as unstoped drifts and crosscuts, though many stopes stand for years with small support. Because of the strength of the rock, many drifts 50 years or more old are still accessible. Most of the stopes, active and abandoned, are continually settling, and in the older stopes there is a continuous succession of cracking noises produced by the settling of the roof. Subsidence, however, is seldom complete, and it is possible to find passageway through many old stopes in which partial subsidence has taken place.

Rock bursts or air blasts [61] are not of common occurrence and are confined to the lower parts of the deeper mines.

There is a marked slabbing on the 9,000-foot level of the North Star mine, where the granodiorite breaks in flat slabs parallel with the sides or roof of the drifts. Occasionally the slabs break off with explosive violence but usually the cracking is gradual and the drifts are slowly enlarged by the loosening and falling of the slabs. This breaking makes it possible to obtain excellent thin, flat specimens of the smaller veins.

When the 8,600-foot pump station at the North Star mine was being cut, violent rock bursts were of frequent occurrence. Sometimes large slabs weighing several hundred pounds would be hurled for 20 feet across the station and be broken on the opposite wall. Slabbing ceased soon after the completion of the station, when the differential stresses in the granodiorite were adjusted.

The 8,600-foot level is 3,500 feet beneath the surface, and the wall rock supports a load of approximately 4,000 pounds to the square inch. Merrill [62] lists the crushing strength of several granites, ranging from 13,190 to 30,888 pounds to the square inch, and Day [63] reports the crushing strength of the granodiorite at Rocklin, Calif., to be 21,104 pounds to the square inch (average of three tests). On the basis of these figures, the weight of the overburden at the 8,600-foot level of the North Star mine is between one-third and one-seventh of the crushing strength of the rock. As many of the older determinations were made on poorly shaped cubes, which gave a low figure, it appears more probable that a crushing strength of 30,000 pounds to the square inch can be assumed for the Grass Valley granodiorite and that the weight of the overburden is near one-seventh of the crushing strength of the rock.

In general, pressure bursts at Grass Valley occur below a vertical depth of 3,000 feet in freshly opened workings and cease after a few months. Though usually smaller and less violent, these rock bursts are similar to those encountered in the deep veins of the Witwatersrand, South Africa, in the Kolar gold field, India,[64] and in the Lake Superior copper mines.[65] At Grass Valley pressure bursts may be expected to increase in number and violence as the mines are deepened.

[61] Also called pressure bursts, strain bursts, rock thrusts, blistering, spitting, sudden flaking, bumps, crumps, and quakes. Report of the Witwatersrand Rock Burst Committee, Union of South Africa, Cape Town, 1925.

[62] Merrill, G. P., Stones for building and decoration, 3d ed., p. 508, John Wiley & Sons, 1903.

[63] Day, W. C., Stone: U. S. Geol. Survey 20th Ann. Rept., pt. 6, p. 359, 1898.

MINE WATERS

Quantity.—Mine waters in the district present no unusual engineering difficulties. Surface waters descend along open crossing fractures, and there is a rapid increase in pumpage from shallow workings after protracted heavy rains. In the deeper levels the increase in rate of flow as a result of heavy rains is much less apparent. Complete pumpage records for the North Star mine extending from January 1928 through April 1929, a period of 16 months, were assembled by Mr. Loufborrow. The pumpage reached a maximum of 700,000 gallons daily in April 1928 and a minimum of 570,000 gallons in February of the same year, but the pumpage curve could not be satisfactorily correlated with the precipitation record.

The storage capacity of the rocks appears to be great, for water accumulated during periods of heavy rain is stored in the network of fissures near the surface and slowly discharged into the deeper mine workings through the stronger and more open crossings. In general, deep workings are remarkably dry except at strong crossing zones. Many such crossings are very wet and discharge water throughout the year.

The following table prepared by Robert Cannon, of the Empire Star Mines Co., gives the average daily pumpage rate of the Pennsylvania and Empire mines and the zones in which the water accumulates. The data are shown graphically in figure 9.

Flow of mine waters at various depths in Empire and Pennsylvania mines

Pump station	Zone of inflow	Average pumpage rate (gallons a minute)
Empire mine		
1,100 level	1,100 to drain tunnel	350
2,200 level	2,200 to 1,100 level	100
3,400 level	3,400 to 2,200 level	120
3,800 level	3,800 to 3,400 level	50
4,600 level	4,600 to 3,800 level	224. 65
5,400 level	5,400 to 4,600 level	12. 49
6,200 level	6,200 to 5,400 level	28. 46
7,000 level	7,000 to 6,200 level	14. 40
	7,000 to drain tunnel	900
Pennsylvania mine		
1,100 level	1,100 to drain tunnel	80. 00
1,400 level	1,400 to 1,100 level	258. 30
1,700 level	1,700 to 1,400 level	420. 00
2,100 level	2,100 to 1,700 level	18. 75
2,500 level	2,500 to 2,100 level	56. 25
	2,500 to drain tunnel	833. 30

[64] Smeeth, F., Air blasts and quakes on the Kolar gold field: Mysore Geol. Dept. Bull. 2, 1904. Moore, E. S., Air blasts in the Kolar gold field, India: Am. Inst. Min. Met. Eng. Trans., vol. 61, pp. 77-84, 1919. Crowle, P. J., Notes on ground movements and methods of support in deep mines (the Kolar gold field): Inst. Min. Metallurgy [London], Trans., vol. 40, pp. 77-144, 1931.

[65] Crane, W. R., Rock bursts in the Lake Superior copper mines: U. S. Bur. Mines Bull. 309, 1929.

Chemical character.—Two ½-gallon samples of mine water were analyzed by C. S. Howard of the Geological Survey. Sample A was collected at the face of a crosscut on the 2,400-foot level of the Pennsylvania mine, where a drill hole in the face flowed 16 gallons a minute. The crosscut from which the sample was taken is about 1,300 feet vertically below the surface and is in granodiorite. Sample B came from a strong crossing flowing about 3 gallons a minute on the west end of the 4,400-foot level of the North Star mine, about 1,500 feet below the surface. The wall rock is diabase. The composition of the waters is shown graphically in figure 10, where the heights of the several sections correspond to the quantities of the radicles, expressed in terms of combining weights rather than in parts per million.

Analyses of Grass Valley mine waters

[C. S. Howard, analyst. Parts per million]

	A	B
SiO_2	49. 0	32. 0
Fe	2. 5	1. 8
Ca	114. 0	263. 0
Mg	14. 0	12. 0
Na	11. 0	11. 0
K	6. 4	3. 5
CO_3	0. 0	0. 0
HCO_3	176. 0	212. 0
SO_4	202. 0	529. 0
Cl	4. 0	2. 0
NO_3	(1)	(1)
Hardness	342	707
Ignition loss	15	33
Total dissolved solids	496	1, 009

1 Less than 1.

A. Water-resources laboratory, no. 10215.
B. Water-resources laboratory, no. 10216.

Both are essentially calcium bicarbonate and sulphate waters and the principal difference, as is clearly shown in the diagram, is the greater calcium sulphate content of the sample from the diabase of North Star mine. While broad generalizations cannot safely be based upon two analyses, it appears reasonable to attribute the greater calcium sulphate content of the diabase water to the generally higher pyrite content of the diabase and porphyrite and to their finer grain. Thus the oxidation of pyrite liberates sulphuric acid which attacks the secondary calcite and so yields a calcium sulphate water.

Lindgren[65a] collected samples of two mine waters from the Nevada City area, and the analyses are given in the table following.

In order to compare them with the Grass Valley waters, the CO_3 was recalculated as HCO_3 and the equivalents plotted in the diagram (fig. 10). Both samples are essentially calcium bicarbonate waters poor in sulphates As both water samples came from shallow depths, having been taken on the 400-foot levels of the Federal Loan and Mountaineer mines, this low sulphate content may be due to the fact that they represent waters which have not long been in contact with the country rock or which have been confined in the zone of weathering, in which most of the pyrite has already been oxidized.

65a Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 121.

Analyses of Nevada City mine waters

[W. F. Hillebrand, analyst. Parts per million]

	C	D
SiO_2	32. 7	41. 4
Fe_2O_3 } Al_2O_3 }	4. 2	1. 8
Ca	33. 6	44. 3
Mg	5. 7	3. 3
Mn	. 27	1. 9
Na	13. 4	13. 7
K	1. 0	1. 6
CO_3	141. 8	146. 6
SO_4	7. 7	7. 8
Cl	3. 2	3. 1
S	1. 1	

All the waters analyzed are of meteoric origin, and their chemical character is dependent upon the rocks through which they have passed. Limonite, gypsum, and a small quantity of calcite are being deposited today. There is no evidence of the present existence of ascending magmatic waters.

MAGNETITE-PYRRHOTITE VEIN

The crosscut on the extreme north end of the 4,200-foot level of the Empire mine (pl. 35), cuts the Crown Point vein, unique in the district because of its content of pyrrhotite and magnetite, which are regarded as characteristic of high-temperature or hypothermal veins. The vein strikes northwest and dips 75° NE. The fracture itself is 2 feet wide, but bordering it for 8 feet on each side is a zone of sheared porphyrite highly impregnated with magnetite. The vein filling is composed of quartz, pyrite, pyrrhotite, and magnetite, with a large amount of later carbonates. The vein carried less than 0.1 ounce in gold.

The Crown Point mine, on the eastern edge of town, was opened in 1886 and worked from time to time thereafter. Pyrrhotite and magnetite were collected from the dump in 1931. Lindgren[66] states that one bunch of ore with much coarse gold yielded $80,000.

With the exception of a specularite-filled crossing in the Empire mine and a deposit of magnetite in diabase in Diamond Creek, 4,000 feet east of the Omaha mine, the Crown Point vein is the only hypothermal vein deposit in the district known to the writer.

GOLD QUARTZ VEINS

This section of the report is wholly descriptive. The principal features of the fractures and fillings of the gold-quartz veins are described in some detail. An attempt is made to generalize the descriptions as broadly as possible rather than to assemble the detached examples that are to be found in the section on mine

66 Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 231.

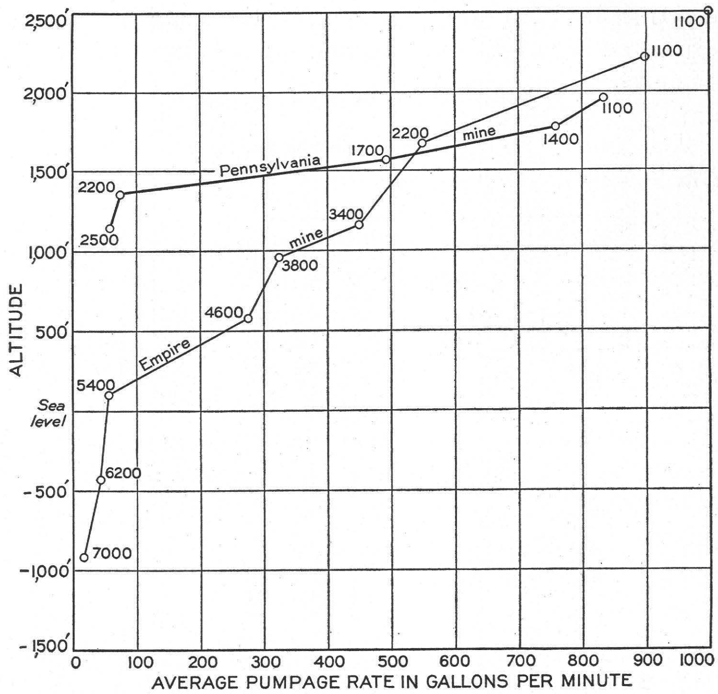


FIGURE 9.—Graph showing pumpage rate at various levels in the Empire and Pennsylvania mines. Main pumping stations are represented by level numbers.

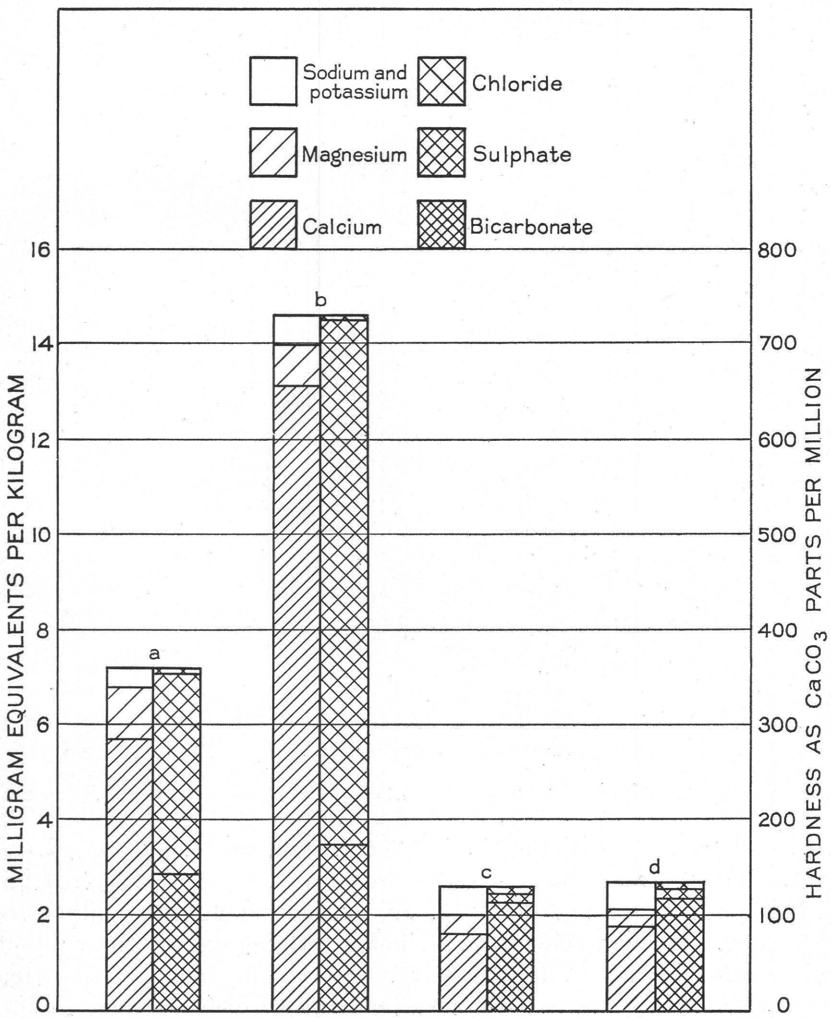


FIGURE 10.—Graphic representation of analyses of mine waters: a, Granodiorite water, Pennsylvania mine; b, Diabase water, North Star mine; c, Calaveras water, Federal Loan mine, Nevada City, from a fissure in footwall flowing 2 gallons a minute (after Lindgren); d, Granodiorite water, sample from Mountaineer mine (Black Prince vein), Nevada City, from a small flow on the footwall of the vein (after Lindgren).

descriptions. An interpretation of the material here presented is given in the section on the origin of the deposits.

DISTRIBUTION AND ATTITUDE

The predominance of northward-striking veins is conspicuously shown in figure 11, taken from the accompanying geologic map (pl. 1). Somewhat less conspicuous are the veins of westerly and northwesterly strike, such as the North Star, the New York Hill, and the veins in the serpentine area.

Geographically, the veins fall into several groups. Immediately southwest of town are the northward-striking veins of the Golden Center, Gold Hill, and Massachusetts Hill group, which dip both east and west. Farther south are the northwestward-striking veins of the North Star and New York Hill mines, which dip northeast. In the granodiorite in the southern part of the quadrangle is the Omaha-Hartery-Allison Ranch group, striking north and dipping west. On the east side of the quadrangle, extending from Grass Valley to the south end, are the veins of the Pennsylvania-Empire-Osborne Hill group, which strike north and dip west. Near the granodiorite contact are a few veins with strikes about parallel to the contact but with opposite dips. Finally, in the serpentine area are the east-west and northwest veins of the Idaho-Maryland group, most of which dip south. Mine workings on most of the veins have exposed other

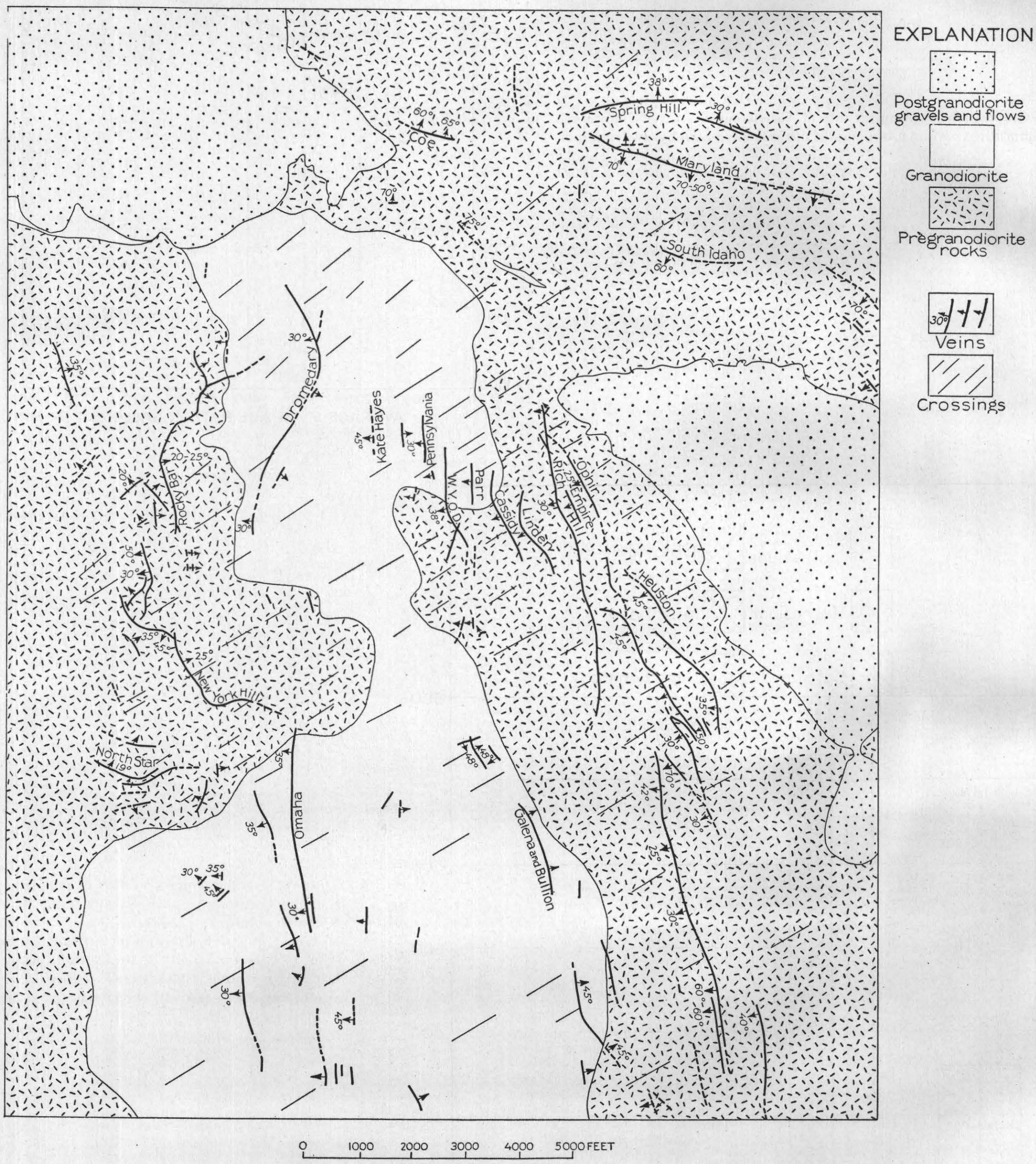
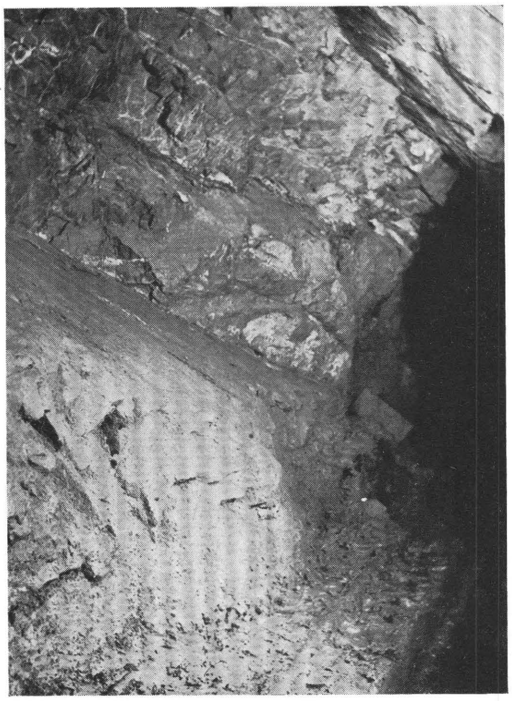
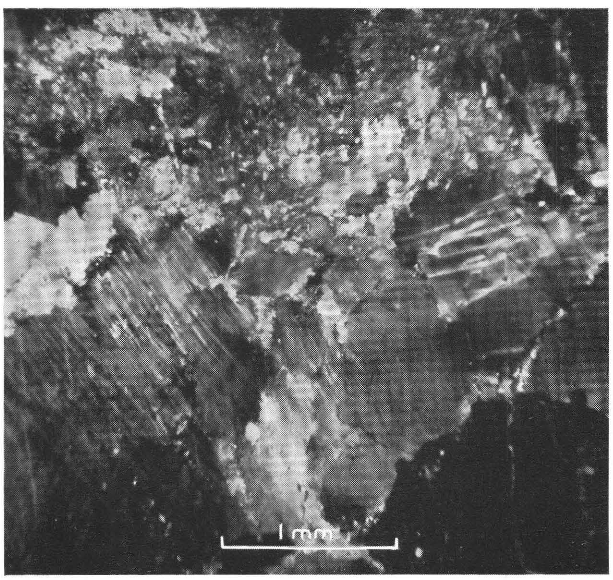


FIGURE 11.—Outline map of the Grass Valley quadrangle showing vein outcrops and the strike of the crossings. After Lindgren's geologic map.

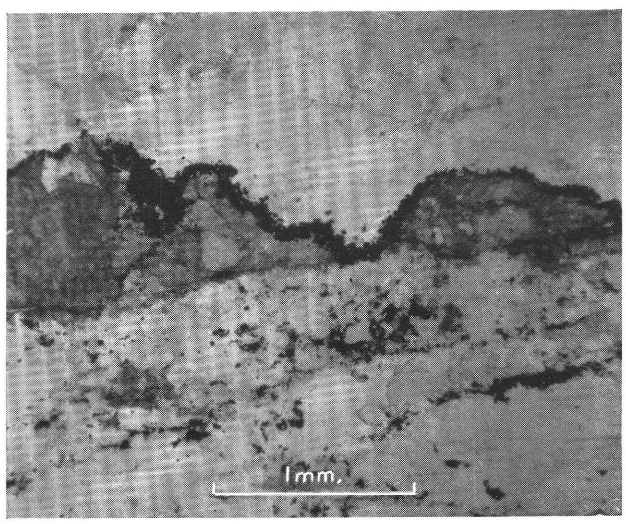


A. STRONG WALLS IN GRANODIORITE WITH INTERSTITIAL BRECCIA ZONE.
Empire mine, 5,000-foot level.

B. GOUGE-FILLED VEIN FRACTURE.
North Star mine, 6,000-foot level.



C. STRAINED QUARTZ WITH LATER CARBONATES.
Empire mine, 3,800-foot level. Crossed nicols.



D. LATE PYRITE (BLACK) AND CARBONATES ON A SHEAR ZONE IN VEIN QUARTZ.
North Star mine, No. 3 vein, 9,000-foot level. One nicol.

VEIN WALLS AND SHEARED QUARTZ.

fracture zone are more complex, and slight changes in the strike and dip of the vein occur where fractures converge at low angles. Most walls of strong veins show large grooves and ridges, commonly 5 to 10 feet in width and with 1 foot or more of relief. Irrespective of the strike and dip of the vein, these grooves generally pitch to the northeast or southwest, or more exactly

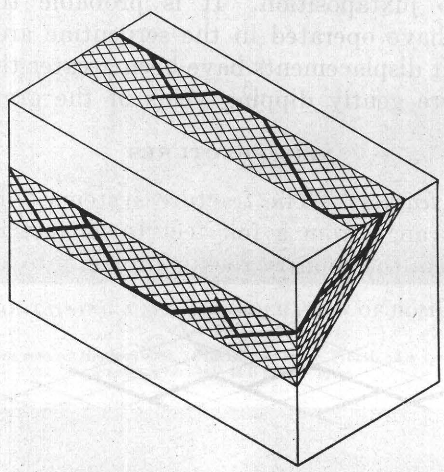


FIGURE 13.—Diagram illustrating Duggleby's "rhombohedral theory" in which the rhombs are contained between main vein walls.

stated, a vertical plane embracing the groove or ridge generally strikes northeast.

In several stopes in both the North Star and Empire mines the hanging wall shows remarkable continuity and freedom from low-angle splits, and it therefore stands with surprisingly small support. One of the fortunate features is the relative freedom from caving in the competent rocks of the district. Many drifts in granodiorite and diabase that have been abandoned for 30 years or more are accessible today. Even many old stopes can comfortably and safely be traversed by keeping to their edges, where caving has been least.

In contrast to such competent rocks as granodiorite, diabase, and even the Calaveras formation, the serpentine requires constant timbering, and both stopes and drifts cave as soon as support is neglected. In consequence, old workings in serpentine areas are all inaccessible.

Diverging walls and splits.—At irregular intervals along the drifts secondary walls leave the main vein walls, usually at low angles. Commonly these diverging walls are tight, barren fractures and are as abundant in one vein wall as in the other. A few secondary walls carry quartz or calcite and are followed by drifts. Most of these drifts are short, as evidence of mineralization decreases away from the main vein and the secondary wall becomes tight and barren. Particularly is this true where the mineralized secondary wall forms a spur at a sharp turn in the main vein. Very often in mining the spur is followed rather than the vein, and it is only when the spur vein is lost that the main vein is recognized and drifting is resumed along it. Reference to figure 13 suggests the infinite possibilities of such wrong leads.

Many drifts have followed the wrong wall for considerable distance. The drift pattern of almost any mine map of the district reveals such situations. Particularly conspicuous is the 1,900-foot east drift of the North Star mine (pl. 26), where a weak vein segment converges with a strong vein. The drift following the good vein toward the shaft from the intersection parallels the earlier drift, a short distance in its footwall, for 400 feet.

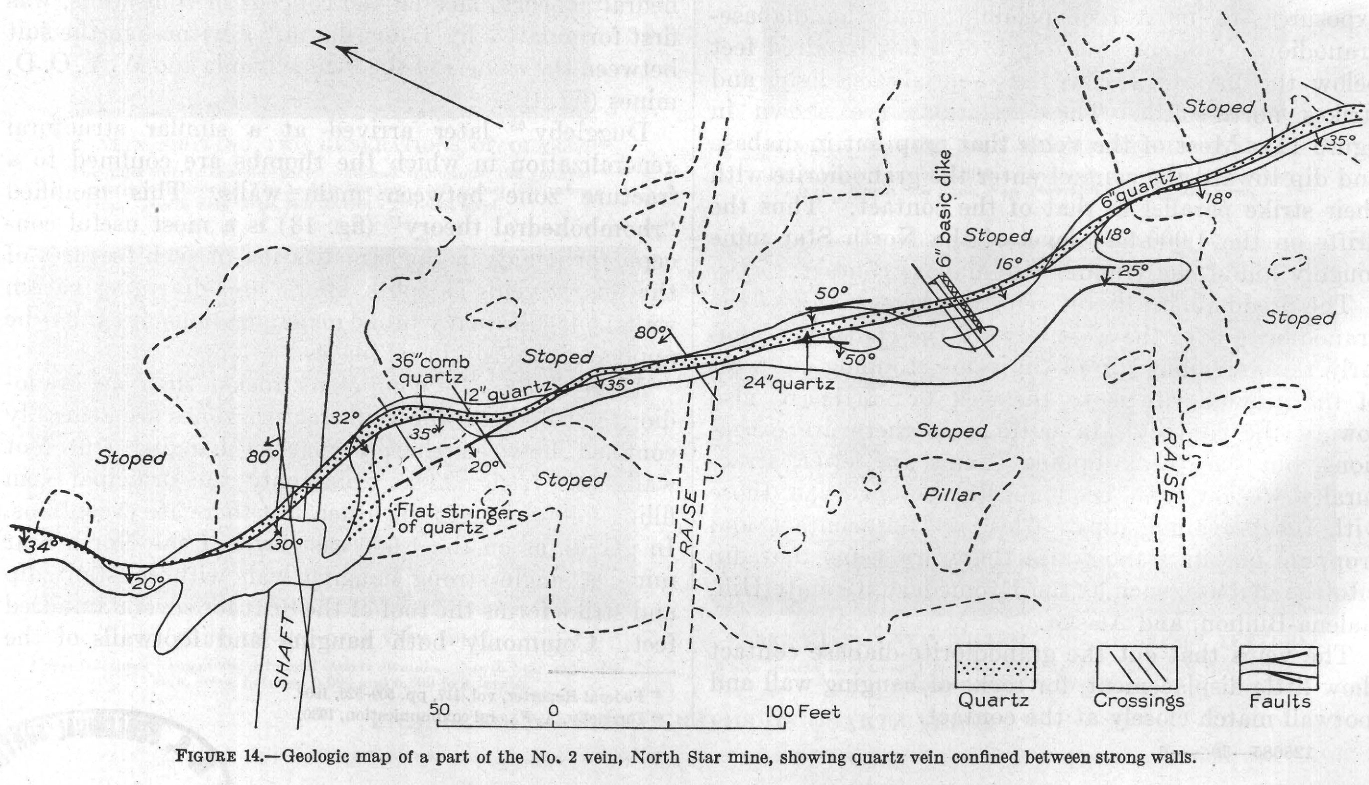


FIGURE 14.—Geologic map of a part of the No. 2 vein, North Star mine, showing quartz vein confined between strong walls.

Commonly a vein segment is progressively weakened by a series of roughly parallel secondary walls that leave either the main hanging wall or main footwall. As each split leaves, the vein fracture becomes narrower, the gouge less abundant, and the advancing face less promising. Finally only a narrow, tight fracture remains. Such a condition is diagrammatically shown in figure 16. The diverging walls, in many places, come together again, and the amount of vein material increases as the splits converge, giving a second vein, parallel to the first and lying in the wall into which the splits turned. Long mining experience in the district has shown that a crosscut to intersect the new vein should not be driven too soon or the new vein will not be found.

Commonly neighboring veins are connected by fractures that are locally mineralized and elsewhere barren. One of the accepted and successful methods of exploring unknown ground is to drift on a fracture, preferably a mineralized one or, in its absence, one that is barren. The "Connecting vein" of the North Star mine—a narrow barren fracture—was followed from the X vein for 800 feet where it led to the No. 2 vein, the richest in the deep levels of the mine. At some places, however, persistent drifting on fractures, both barren and mineralized, has been unproductive.

Possibly the most valuable attribute of the mining engineer, geologist, or mine foreman in Grass Valley is the ability to remember the detailed appearance of old working faces and to interpret the structural subtleties of the diverging walls met in current operations in the light of past experience. When the vein is good the mine manager's worries are few, but when it is poor he is in sore need of some guide to ore. Skill in using the guidance of secondary walls and crossings comes only with long experience underground in the district and is vested mainly in those men who watch the faces advance from day to day.

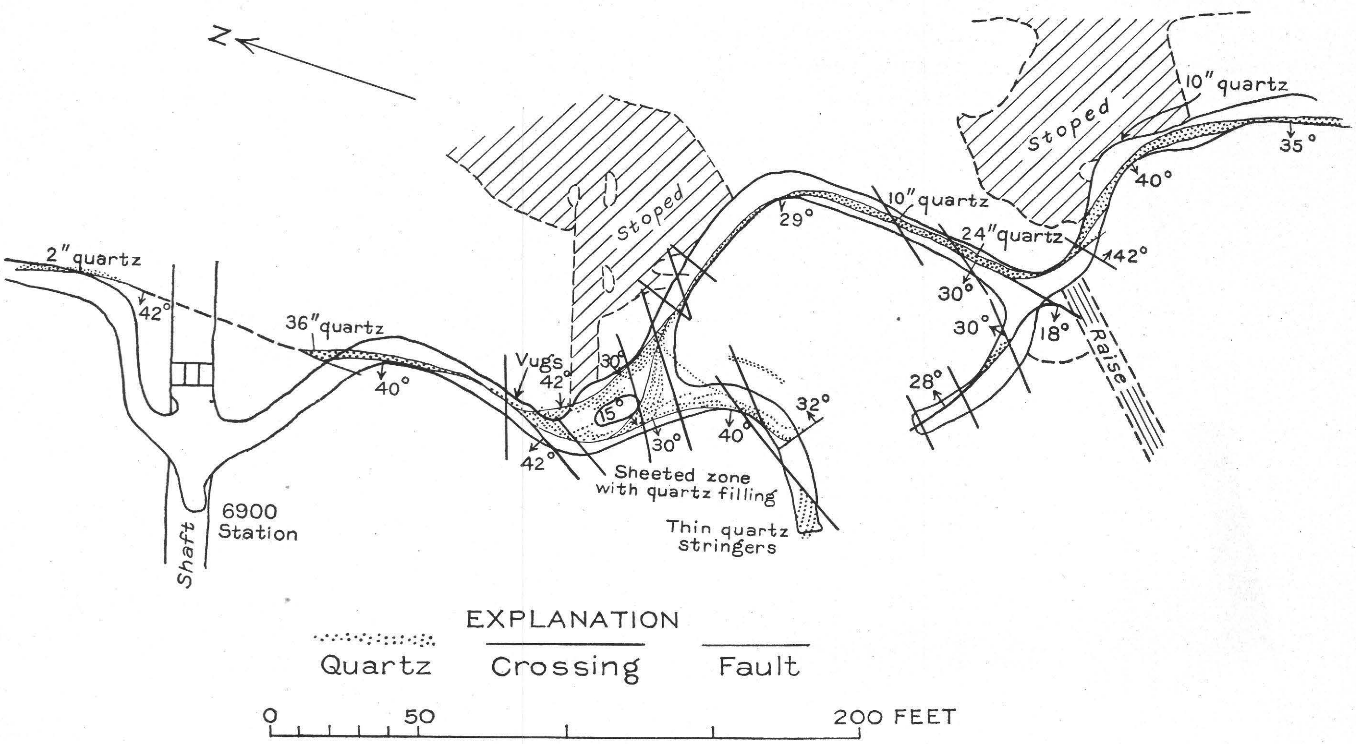


FIGURE 15.—Geologic map of a part of the 6,900-foot level, No. 2 vein, North Star mine, showing complex vein structure with numerous splits and cross-over walls.

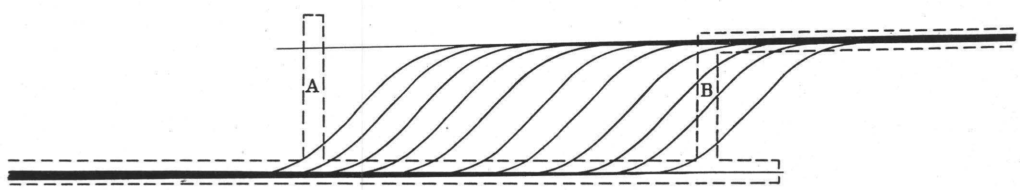


FIGURE 16.—Diagrammatic plan illustrating the manner in which one vein weakens as a parallel vein strengthens. A drift, driven from left to right, encountered a number of parallel diverging splits. Crosscut *A* would intersect only a weak fracture, whereas crosscut *B* would cut the new vein beyond the convergence of most of the splits. This is an important mining concept in the district, for if the crosscut is driven too soon the new vein may not be found.

Gouge.—All the veins of the district have some gouge. It may be confined to one or to both walls, or it may cross the quartz from wall to wall. On the narrow tight veins the amount of gouge is small, or it may even be absent on short vein segments where quartz, tightly cemented to both walls, fills the entire vein fracture. Generally, however, gouge as much as several inches or even several feet in thickness is present. With the clayey gouge is generally some coarser material—fragments of country rock or of quartz that has not been finely ground. Such material ranges in size from large angular fragments of wall rock to minute fragments of quartz that impart a gritty feel to the clayey gouge.

Perhaps the thickest gouge occurs on the X vein in both the Empire and North Star mines. This vein commonly has 5 feet or more of gouge between walls, and, unlike most veins of the granodiorite area, requires heavy timbering to keep the drifts open.

A somewhat unusual exposure on the 6,300-foot level, No. 2 vein, North Star mine (fig. 17) shows the following depositional sequence: (1) Quartz combs were deposited on the walls of the vug; (2) a layer of clear ankerite was deposited on the combs; (3) an emulsion of gouge consisting of ground quartz, carbonates, and chlorite flowed into the vug from the faulted crossing; (4) as the solid particles of the gouge emulsion settled ankerite was deposited, cementing the gouge and filling all the open spaces in both vug and crossing.

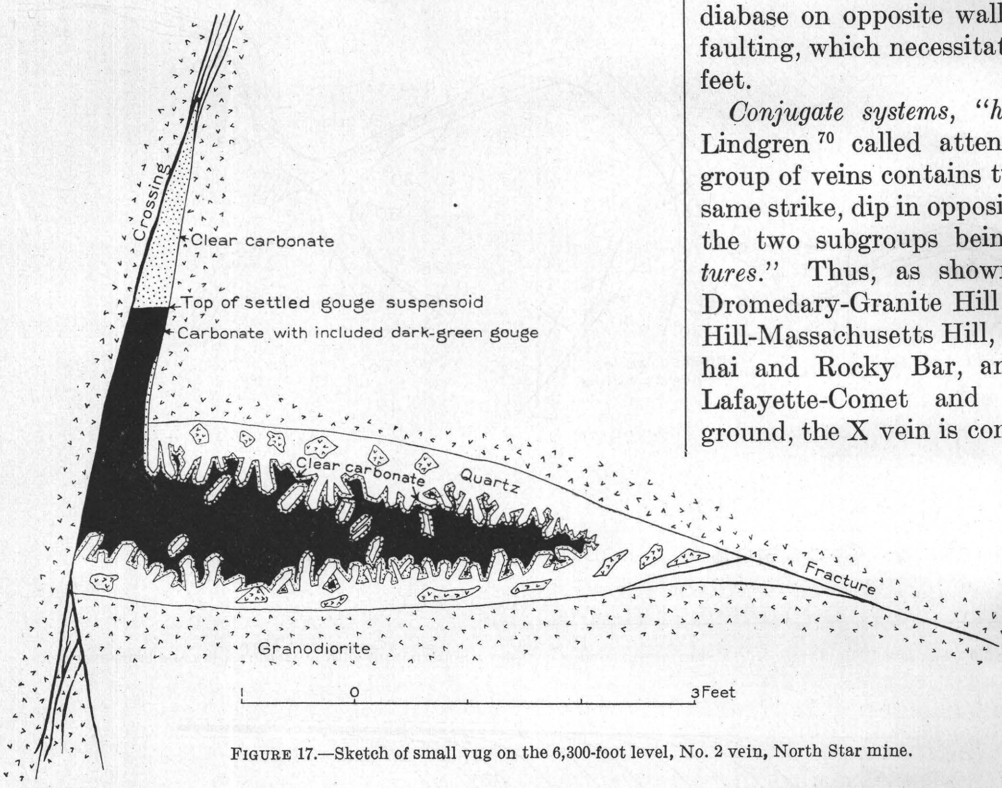


FIGURE 17.—Sketch of small vug on the 6,300-foot level, No. 2 vein, North Star mine.

Displacement on the veins.—The veins of the granodiorite area show little displacement, for the diabase-granodiorite contact, which most of them intersect, is not appreciably offset on the vein fractures. Similarly, many dikes are cut by veins with little or no displacement. Some dikes, however, show reverse displacement of a few feet by the vein fissure.

The greatest displacement measured was on the No. 2 vein of the North Star mine. In the main mine above the 6,000-foot level a quartz-filled crossing has been offset in a thrust direction for a distance of 12 feet in the plane of the raise. As strong grooves and mullions on the walls strike N. 40° E. and indicate the direction of movement, the hanging wall has been thrust to the northeast over the footwall for a net distance of about 20 feet.

The general impression given by the veins of the granodiorite area is that little displacement has occurred and, where some clue to the direction of movement was found, the hanging wall rode up on the footwall.

On the veins of the serpentine area displacements of some magnitude may have taken place, as the hanging and footwalls are commonly dissimilar rocks. H. F. Lynn,[69] who has studied the Spring Hill mine in some detail, interprets the juxtaposition of serpentine and diabase on opposite walls of the vein as the result of faulting, which necessitates a throw of several hundred feet.

Conjugate systems, "hogbacks," and intersections.—Lindgren [70] called attention to "the fact that each group of veins contains two subgroups, which, with the same strike, dip in opposite and symmetrical directions, the two subgroups being designated *conjugated fractures.*" Thus, as shown on the geologic map, the Dromedary-Granite Hill vein is conjugate to the Gold Hill-Massachusetts Hill, the Black Ledge to the Shanghai and Rocky Bar, and the Bullion-Alaska to the Lafayette-Comet and the Ben Franklin. Underground, the X vein is conjugate to the North Star vein and the Newmont to the Empire vein. Other conjugated pairs are shown in the cross sections.

Several veins in the district flatten and reverse their dip, forming "hogbacks," and so do not crop out at the surface. Lindgren's type example for this structure [71] is the New Rocky Bar vein (figs. 53 and 54). Other veins of this type are found on the north end of the Pennsylvania mine above the 700-foot level, in the Brunswick mine on the 400-foot level, and the New York Hill vein on the 600-foot vertical level of the North Star mine (fig. 52). The reversal in dip of the New York Hill vein is particularly well exposed underground. Some mine maps show curved drifts that turn through as much as 180° in following domelike flexures on the vein. All these features, however, make up a very small fraction of the total known vein area, and for the most part, individual veins, although varying from segment to segment, preserve fairly uniform dips and strikes.

The junctions of converging conjugate pairs of veins are not well marked. The inclined shaft of the North

[69] Oral communication, August 1934.
[70] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 169.
[71] Idem, p. 237 and pl. 22.

Star mine follows the North Star vein down almost to the 6,300-foot level, where the shaft intersects the X vein. As the intersection is approached the North Star vein is weakened by diverging fractures, and the vein is lost before the intersection is reached. The North Star vein has not been recognized in the footwall of the X vein. Similarly the A vein has not been found above its intersection with the New York Hill vein nor below the North Star vein (fig. 49), nor has the Newmont vein been traced across the Empire vein. Everywhere the intersection is marked by the dissipation in many diverging walls of one vein or the other.

The junctions of nearly parallel veins that converge at low angles are marked by numerous walls that cross from one vein to the other and from a segment of broken ground near the intersection. Many of these cross-over walls are mineralized.

VEIN FILLING

Material.—Quartz is the principal vein material. Several distinct textural types are described in the section on mineralogy. Briefly, the principal types are (1) comb quartz, forming crusts and lining vugs; (2) massive milky quartz that has a granular texture and has not undergone deformation; (3) sheared quartz, deformed with little or no dilation of the vein and commonly showing "ribbon" or shear-banding structure; and (4) brecciated quartz, formed where vein movement dilated the interwall space. Massive milky quartz is perhaps most abundant and generally makes up most of the vein filling, but the other types are widely distributed, and any or all may be present in a single vein exposure. A schematic diagram showing the types of vein movement under which these textures are developed is shown on page 40. Photographs of underground exposures of quartz veins are given in plates 8, 9, and 10, and photomicrographs of thin sections of quartz in plate 7, *C* and *D*, and in plates 19 to 23.

As previously stated, the vein fractures are rarely simple breaks with a single pair of walls. Rather they are more or less complex fracture zones with many minor walls and with much broken country rock lying between them. The vein filling, which is dependent upon the size and shape of the available openings in complex fracture zones, exhibits all the irregularities of the vein fractures. Some of the weaker veins and smaller secondary fractures diverging from the main veins are filled with comb or massive quartz tightly "frozen" to both walls (pl. 10, *E*). In other vein segments quartz cements brecciated fragments of wall rock, which appear as inclusions in the vein material (pl. 9, *B*). Elsewhere quartz or carbonates fill branching fractures between the main walls (pl. 10, *C*) or thin parallel fractures forming miniature "sheeted ground" (pl. 10, *A*).

The thickness of the quartz vein filling is widely variable. Thicknesses of 3 feet are not uncommon on good veins, but persistent thicknesses of 10 feet or more are rare. Even the most productive veins pinch in places to a narrow quartz seam, or quartz may be wholly lacking.

The photographs of typical veins (pls. 8, 9, and 10) give a far better picture than can be conveyed by written descriptions.

Ankerite and calcite are common gangue minerals but are far less abundant than quartz. Pyrite, galena, and sphalerite are the principal sulphides. These and other vein minerals are discussed in the section on mineralogy.

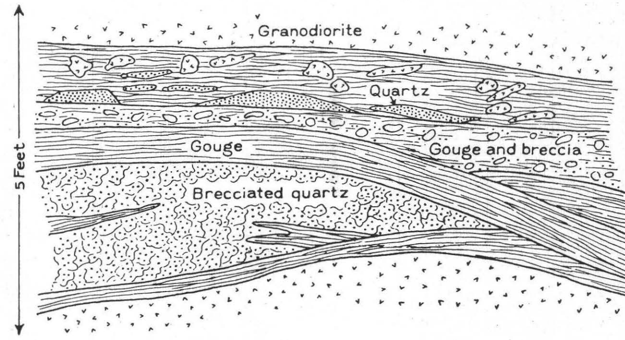


FIGURE 18.—Sketch of No. 1 vein, 6,600-foot level, North Star mine, showing brecciated quartz cut by later gouge. Within a short distance along the vein distinct intersecting gouge zones indicate at least four periods of movement.

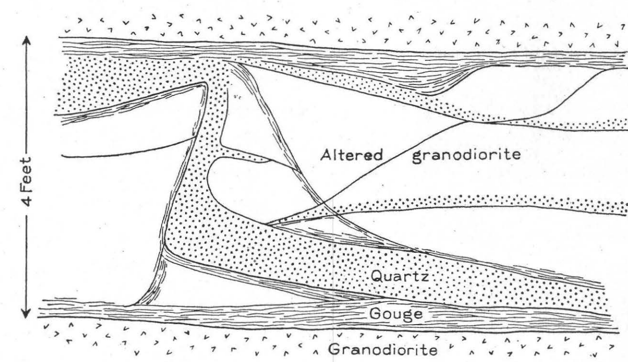


FIGURE 19.—Sketch of No. 1 vein, 7,200-foot level, North Star mine, showing quartz cross-over from foot wall to hanging wall. Under the microscope the quartz shows strain shadows and granulation zones, possibly formed during the postquartz movement marked by gouge zones on both walls.

Evidence of recurrent quartz deposition.—Most of the larger veins have more than one generation of quartz. Most underground vein exposures show two or more generations that can be recognized by differences in color, texture, or intersecting relations. Plate 8, *C*, illustrates a simple occurrence in the North Star mine of two generations in which the inclusion-filled quartz is the older and the band of ribbon quartz is the younger. In many underground exposures gouge seams cutting the older quartz form walls upon which younger quartz is deposited. A fairly complex depositional history is sketched in figure 18. Brecciated older quartz is commonly cemented by younger quartz. Where the generations differ in color because of included material, they stand in sharp contrast (pl. 8, *F* and *C*).

In most places the succeeding generations are recognizable, because vein movement has altered the texture of the older quartz and opened new channels in which the younger quartz was deposited. Thus deposition has alternated with vein movement, and both quartz deposition and vein movement have been repeatedly recurrent. Movement continued after quartz deposition had ceased and is recorded by similarly deformed carbonates.

Ore.—Gold occurs both in quartz and in the sulphides. The gold in quartz is free-milling and is mainly recovered by amalgamation, and that in sulphides by cyanidation.

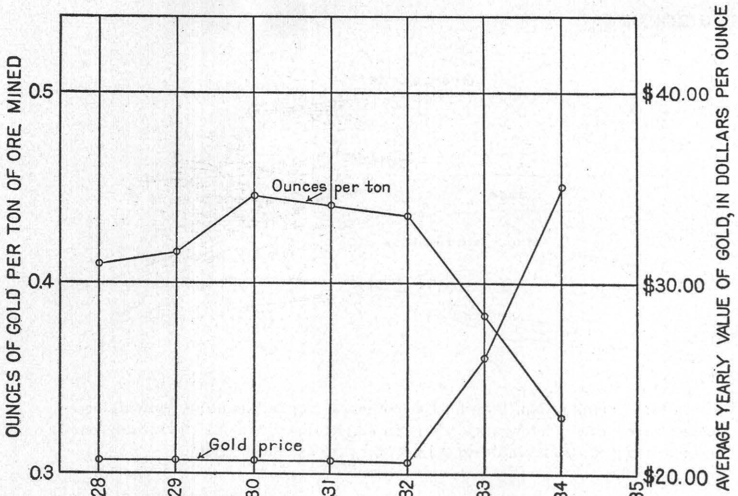


FIGURE 20.—Grade of ore mined in the Empire-Star mines between 1928 and 1934.

Speaking broadly, high-grade ore that contains few sulphides is mainly sheared or ribbon quartz rather than comb or massive milky quartz, possibly because the sheared type offered better channels for the gold-depositing solutions than the denser types. A photomicrograph of gold in sheared quartz is shown in plate 13, *A*.

Pyrite, galena, and sphalerite are generally gold bearing, and their presence in a vein, particularly galena, is regarded as a favorable indication. Arsenopyrite and chalcopyrite, though rarer, are also favorable minerals. All the sulphides form sites for the deposition of gold, which is attached to the sulphide crystals and fills cracks in the pyrite (pl. 14, *A*, *B*). Typical sulphide ore is shown in plate 11.

In the early days of mining in the district only high-grade free-milling ore was mined, and "specimen" ore showing coarse gold to the unaided eye made up a larger percentage of the total ore than it has in later years. Today specimen ore is by no means rare, and most of the mine offices have collections of spectacular ore samples showing coarse gold. However, the average gold content of ore profitably mined in the district in the 20-year period between 1910 and 1930 does not greatly exceed half an ounce to the ton.

In 1933 the price of gold, which hitherto had been fixed at $20.67 an ounce, began to rise. The effect of this increased price on the grade of ore mined at the Empire-Star is shown in figure 20.

The silver content of most of the ore is low. Between 1911 and 1920 the Empire mill recovered only 0.2737 ounce of silver for each ounce of gold.

CROSSINGS

Within this district the term "crossing" has been applied to vertical or steeply dipping fractures that strike northeast. In some places they are simple fractures; elsewhere they form sheeted fracture zones several feet wide. Some of the crossings are tightly closed; others are open and form watercourses through which surface water descends into the mine workings. Some have gouge; others have none. In contrast to the veins, few crossings contain quartz. Detailed underground mapping shows that most individual crossings are rather short, but locally some few zones are relatively persistent on the strike and in depth. Although there is little displacement along either vein or crossing walls where they intersect, offsets of both kinds occur. Crossings are significant structural features in an economic sense, because changes in width and character of the vein quartz and in the gold content commonly occur where crossings intersect the vein.

Structural relations.—Crossings are widely distributed in the competent rocks, such as diabase and granodiorite, and less so in serpentine and amphibolite schist. They are not conspicuous in the generally poor surface exposures, but underground they are met at short though irregular intervals along the drifts and crosscuts. The block diagram of the No. 2 vein, North Star mine (pl. 33), illustrates their general distribution and characteristic lack of individual continuity.

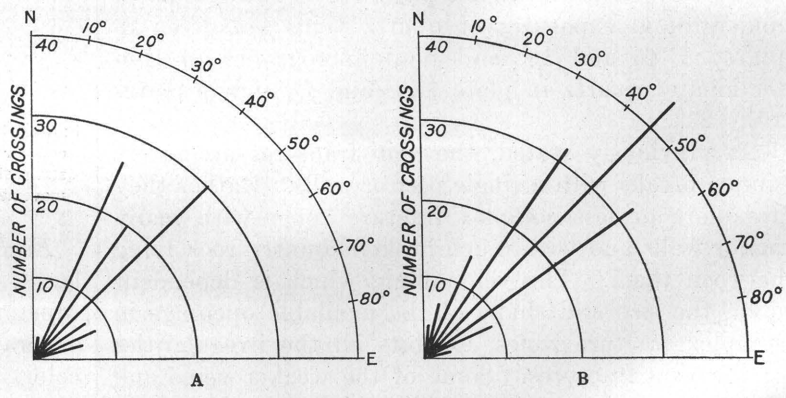


FIGURE 21.—Strike of crossings. Length of line indicates the number of crossings striking in each 10° arc. A, Empire mine, 4,200- to 7,000-foot levels inclusive; 101 crossings plotted; B, North Star mine, drifts on No. 2 vein; 144 crossings plotted.

The strike-frequency distribution of the crossing fractures in the lower levels of the North Star and Empire mines is shown in figure 21. Most of the crossings are vertical or nearly so, and dips of less than 70° are rare.

Most crossings are simple joints that can readily be traced across a drift or through a stope. In places several parallel joints make up a crossing zone, some of which are 20 feet or more in width. Rarely are such crossing zones so broken as to be described as shear zones. Conspicuous examples of open crossings are found near the bottom of the shaft in the Golden Center mine, on the footwall crosscut on the 1,400-foot level of the Pennsylvania mine, and in the west end of the 4,400-foot level of the North Star mine. In the upper and long-abandoned workings of most of the mines large stalactites and stalagmites of hydrous iron oxide have been deposited by water descending on crossings.

Many crossings show evidence of movement in slickensided walls and gouge filling, but where these crossings intersect contacts of dissimilar rocks that might furnish some measure of the relative displacement of the walls the offset is small and is measured in inches rather than in feet.

As most of the postgranodiorite dikes of the district also strike northeast, they might well occupy early crossing fractures that were opened soon after the consolidation of the granodiorite. In several places later crossings have developed on one and even both sides of these dikes (fig. 4).

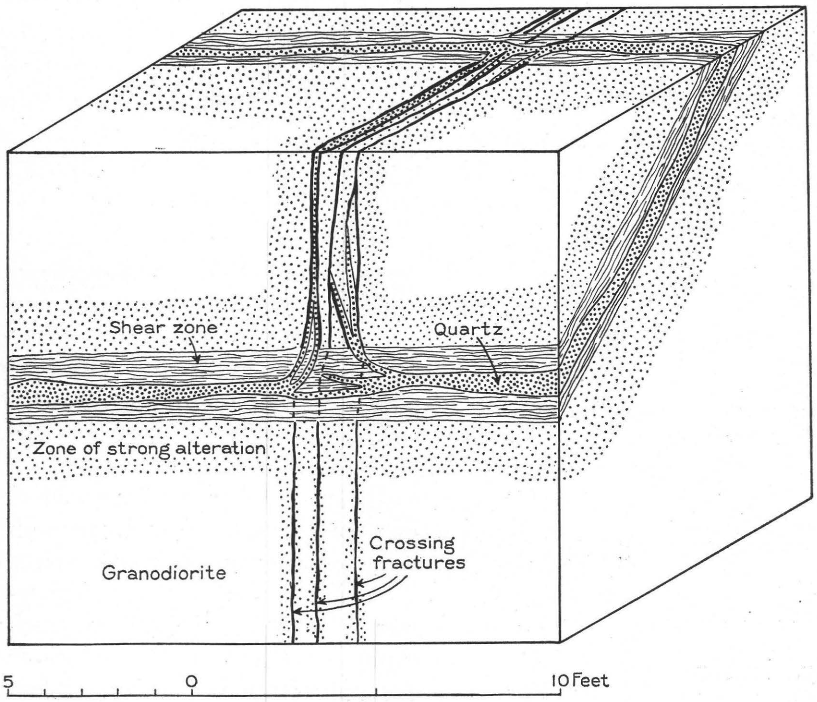


FIGURE 22.—Intersection of vein and crossing without displacement on either fracture. North Star mine, No. 3 vein, 8,600-foot level.

Although most crossings intersect veins without displacement of either vein or crossing (fig. 22), exceptions are rather common. Figure 23 shows a crossing offset by a vein and figure 24 shows a vein offset by a crossing. Just as movement on vein fractures was long continued, as is witnessed by younger quartz cementing older quartz breccias, so movement on crossings has been intermittent, probably beginning soon after the consolidation of the granodiorite and continuing after vein deposition had ceased.

A possible explanation for the change in character of vein material at crossing intersections is illustrated in figure 25. The crossings break the vein into segments, each of which may open or close more or less independently of the adjacent ones. Thus the central vein segment in the figure opens (B) and is filled with quartz (C). Later the whole vein opens (D) and more quartz is deposited (E). As it is known that movement on both veins and crossings was recurrent and that quartz deposition alternated with such movement, the mechanical concept illustrated in the figure can be adapted to fit most observed examples of change in vein character at crossing intersections.

Mineralization on crossings.—Most crossings are not mineralized, but exceptions are by no means rare. The principal vein minerals, quartz, carbonates, chlorite, sericite, pyrite, galena, and sphalerite, are found also in crossings. In most places the crossing mineralization

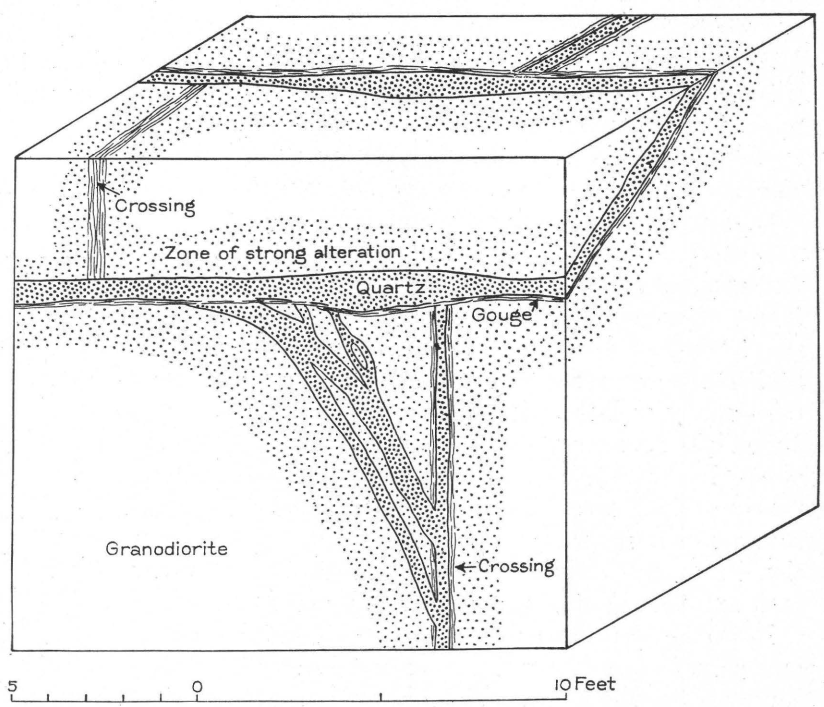


FIGURE 23.—Crossing offset by a vein fracture. North Star mine, No. 3 vein, 9,000-foot level.

was greatest at vein intersections and decreased away from the vein. Crossings that intersect two neighboring veins or two or more quartz strands in a single vein-fracture zone are usually mineralized between the intersections, forming "cross-overs" from vein quartz to vein quartz. Some of these "cross-overs" contain appreciable amounts of gold.

Knaebel [72] made a detailed microscopic study of veins and crossing minerals in an attempt to find criteria by which vein quartz could be distinguished from crossing

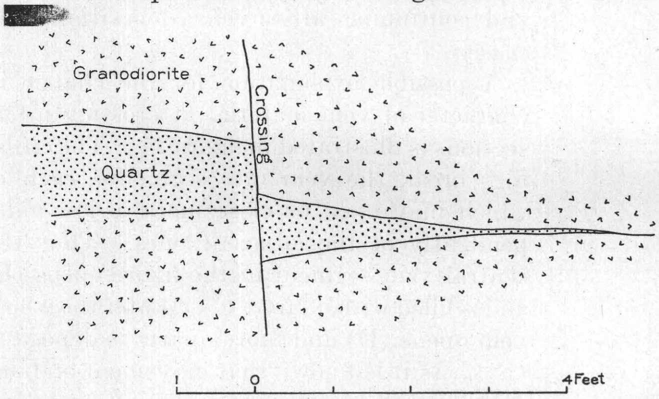


FIGURE 24.—Vein offset by a crossing. North Star mine, No. 2 vein, 7,200-foot level.

quartz as an aid to diamond-drill prospecting. In conclusion he stated:

> This study has shown that neither lean veins nor crossings possess characteristic petrographical or micro-structural features so distinctive or peculiar to themselves as to constitute definite criteria for differentiation. In fact, the leaner a vein becomes in sulphides the more striking microscopic resemblance it bears to a typical crossing.

A quartz-filled crossing of unusual width and persistence extends from the 4,600-foot level of the Empire mine, where it was followed by a short drift from the crosscut to the X vein (pl. 32), southward and downward to the main raise above the No. 2 winze on the 6,000-foot level of the North Star mine, a distance of 2,500 feet on the strike and 400 feet on the dip. It is well exposed on the Empire 4,600-foot level, where 1 to 2 feet of quartz is tightly "frozen" to both walls; on the 5,300-foot level of the North Star, where it is broken into several vertical strands and the quartz contains many wall-rock inclusions; and in the sublevels and stopes between the 5,300-foot and 6,000-foot levels of the North Star mine, where it attains a maximum thickness of 8 feet. Under the microscope the quartz shows much microbrecciation, indicating postdepositional movement on the crossing. It has been faulted, with an offset of 20 feet, by the No. 2 vein.

In the Golden Center mine steeply dipping crossings and gently dipping segments of the Dromedary vein converge on their strikes at low angles. There vein filling commonly follows the steeply dipping crossing fractures from one vein fracture to a parallel one, as is diagrammatically illustrated in figure 26.

[72] Knaebel, J. B., The veins and crossings of the Grass Valley district, Calif.: Econ. Geology, vol. 26, pp. 375–398, 1931.

Many crossings, though themselves free from filling material, furnished channels for mineralizing solutions, as is witnessed by widespread sericitization, carbonization, pyritization, and epidotization of crossing walls.

MINERALOGY

In the following pages the vein-forming minerals are described in alphabetic order, followed by a discussion of their paragenetic relations. Plates 12, 13, and 14 are photomicrographs of vein minerals, and plates 7, *C*, *D*, 15, 16, 17, and 19–23 illustrate quartz textures.

ANKERITE

Ankerite ($CaCO_3$. (Mg, Fe, Mn)CO_3) is widely distributed throughout the wall rocks adjacent to the veins and is an abundant constituent of the veins themselves. It is readily distinguishable from calcite by its higher index of refraction (ω), its relative resistance to staining with copper nitrate solution, and its usual finer-grained habit.

In the porphyrite, diabase, and granodiorite adjoining the veins it commonly replaces all the feldspars and, with sericite, corrodes quartz grains. In the veins it fills vugs and other cavities, cements brecciated quartz, and is in turn cemented and replaced by clean calcite. In old drifts, long exposed to the air, the oxidation of its iron has given the ankerite a buff color. Minute veinlets of both ankerite and calcite cut the vein quartz and extend into the wall rocks. Attempts to find an optical distinction between the ankerite contained in such veinlets and that replacing the feldspars of the wall rock were unsuccessful.

At Grass Valley, as at Alleghany [73] and on the Mother Lode,[74] the total quantity of carbonates introduced into the wall rocks is enormous.

Analysis of ankerite from North Star mine

[J. G. Fairchild, analyst]

	Percentage	Molecular proportion	
CaO	30.64	0.547	1.007
MgO	11.38	.282	
FeO	12.52	.175	
MnO	.31	.004	
CO_2	43.30	.984	.984
H_2O	.40		
Fe_2O_3	.32		
Insoluble	1.46		
	100.33		

Although there appears to be considerable variation in the composition of ankerite from Grass Valley, the accompanying analysis of a sample of the mineral obtained on the 3,400-foot level of the A vein of the North Star mine may be considered as representative. There a minor vein is 2 inches wide. Borders of euhedral quartz combs extend inward from the granodiorite

[73] Ferguson, H. G., and Gannett, R. W., Quartz veins of the Alleghany district, Calif.: U. S. Geol. Survey Prof. Paper 172, p. 46, 1931.

[74] Knopf, Adolph, The Mother Lode system of California: U. S. Geol. Survey Prof. Paper 157, p. 35, 1929.

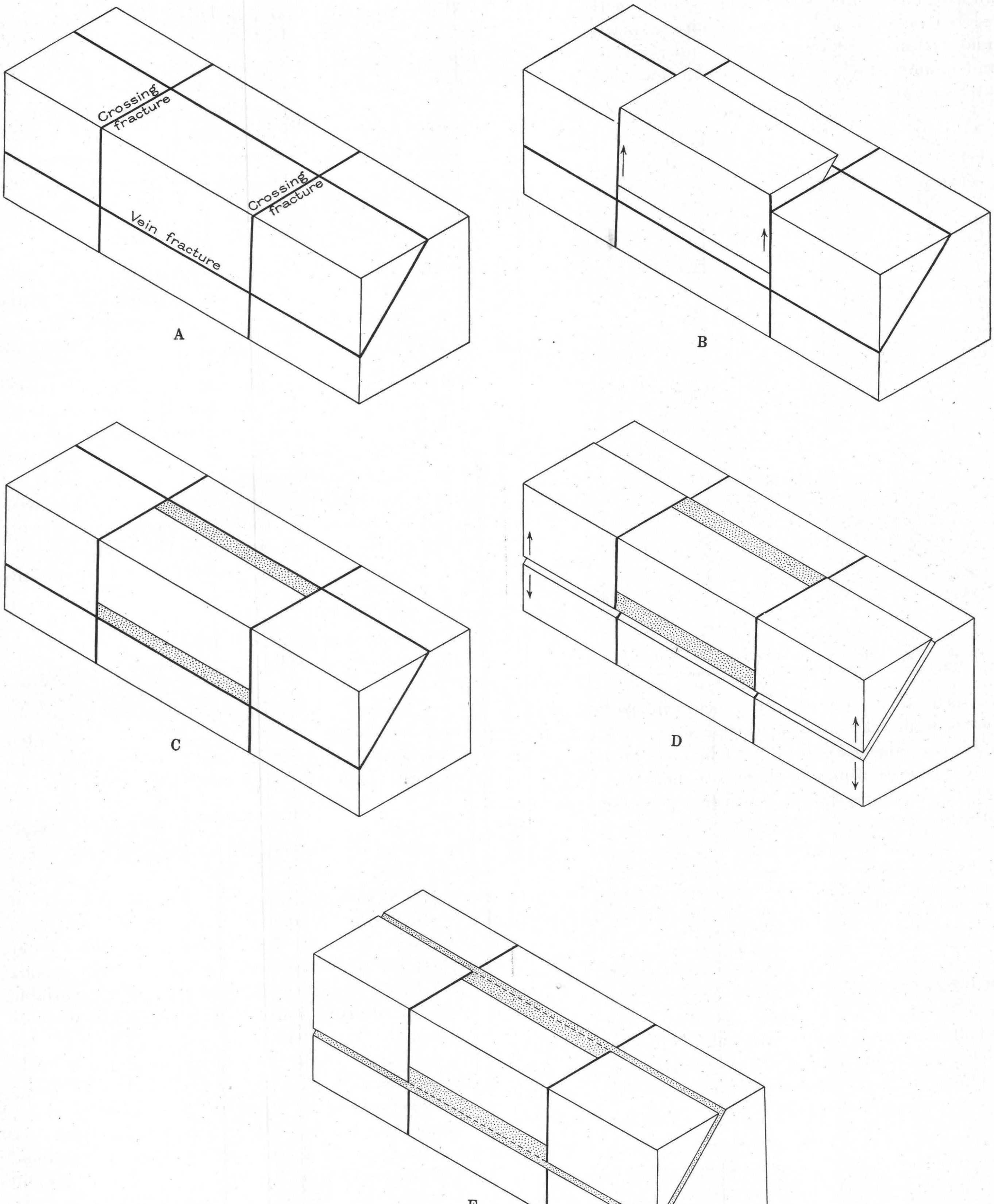


Figure 25.—Diagram illustrating how crossings permit vein segments to open or close independently of the neighboring segments.

walls. The center of the vein is filled with salmon-colored ankerite (ω=1.703) forming a matrix for the quartz combs. Staining with copper nitrate solution and ammonium hydroxide shows a few small areas of later calcite.

ARSENIC

Metallic arsenic forming gray botryoidal masses has recently been found on the north end of the 1,600-foot level of the Empire mine. Mr. Fred Searls, Jr., sent me a

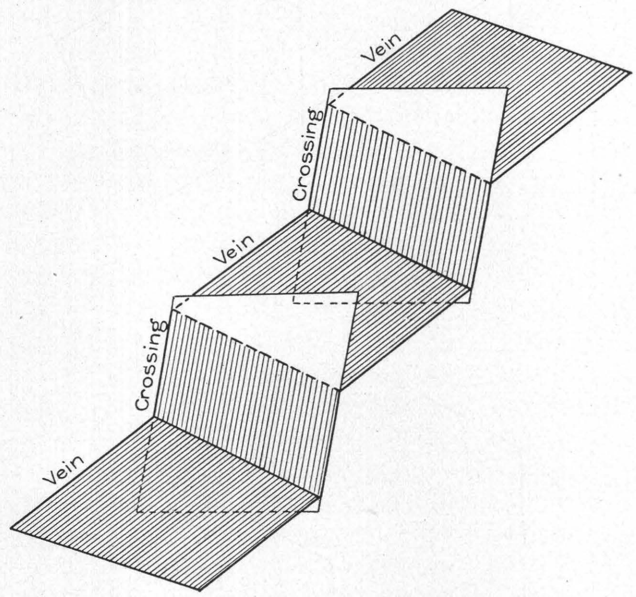


FIGURE 26.—Diagram illustrating the steplike character of the Dromedary vein due to quartz following crossing fractures between vein segments.

specimen about 1½ by 1½ by 2 inches in size composed wholly of metallic arsenic except for a few euhedral quartz crystals enclosed in it. Chemical tests for antimony, bismuth, iron, and silver were negative.

Mr. F. W. Nobs [75] kindly furnished the following note on the locality:

> The vein here is quartz in diabase country, both footwalls and hanging walls. The immediate region is traversed by several crossings which carry white iron pyrite. Most interesting to me is the occurrence of high-grade or free gold ore associated with pyrite and arsenopyrite in this same stope. The botryoidal mineral is rare. As far as I know, only half a dozen pieces about the size of the one sent you were noted. I have a lump that has fine soft free gold within the arsenic.

The 1,600-foot level is about 650 feet vertically below the collar of the Empire shaft and 500 feet below Wolf Creek. Although this depth does not preclude the possibility that the arsenic may be supergene, neither does it establish its secondary origin.

ARSENOPYRITE

In the Nevada City area arsenopyrite (FeAsS) is a common though erratically distributed vein mineral. At Grass Valley it was rarely observed. Ore from the 1,300-foot level of the Empire mine contained fractured arsenopyrite and pyrite with minute blebs of gold (pl. 14, *F*).

[75] Personal communication, April 28, 1937.

Much arsenopyrite is contained in the diabase walls of that part of the Rich Hill shaft which is still accessible from the Empire workings. According to Lindgren [76] the mineral is most abundant in the veins of the Osborne Hill system south of the Orleans mine. None of these workings are now accessible.

From the meager evidence available the arsenopyrite appears to be contemporaneous with the early hydrothermal pyrite.

AZURITE AND MALACHITE

Stains of blue azurite ($2CuCO_3.Cu(OH)_2$) and green malachite ($CuCO_3.Cu(OH)_2$) are common. The source of the copper is chalcopyrite.

CALCITE

Calcite ($CaCO_3$) is a common vein mineral. It occurs in all the veins, and in a few places it is more abundant than quartz. It was deposited later than the ankerite and was frequently observed replacing ankerite. Polished slabs of vein material that have been treated with a strong solution of copper nitrate and then with ammonium hydroxide show the relations existing between calcite and ankerite, for calcite is stained more deeply than ankerite. The calcite is seen to fill the last of the cavities in the veins. Like ankerite, it cements brecciated quartz.

Well-formed scalenohedra as much as 4 centimeters in length were observed in the 7,000-foot level of the Empire mine.

In the Crown Point vein, exposed on the 4,200-foot level crosscut of the Empire mine, calcite is associated with magnetite and pyrrhotite, but its distribution in the vein material indicates that it is a later mineral.

CHALCEDONY

Chalcedony (cryptocrystalline silica, SiO_2) is not a common constituent of the veins. A small amount was observed as a vug lining on the 9,000-foot level of the North Star mine, and similar vug linings were seen at two places on the 500-foot level of the Golden Center mine. In places it cements brecciated vein quartz (pl. 20, *B*, *C*). Such chalcedony contains a variable quantity of admixed limonite, which makes it more or less opaque to transmitted light.

Although most of the chalcedony was deposited late in the carbonate substage, the earliest chalcedony appeared before the last of the gold had been deposited, for Lindgren [77] reports gold "directly embedded" in chalcedony from the Empire and Hudson Bay mines. From his description of the occurrence of chalcedony it appears that this mineral was more abundant in the upper levels of the mines than it is on the deeper levels.

A small amount of clear opal with chalcedony was observed in a few places (pl. 20, *B*).

[76] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), pp. 118–119.

[77] Idem., p. 114.

CHALCOPYRITE

Chalcopyrite ($CuFeS_2$) is sparsely though widely distributed throughout the veins of the district. It belongs to the same age group as sphalerite and galena, being later than the pyrite of the veins.

Much of the sphalerite contains minute rods and dots of chalcopyrite (pl. 14, *D* and *E*). In some specimens they are arranged in straight lines, and in others their arrangement is at random, apparently without regard for the crystallographic directions of the host mineral. Such inclusions of chalcopyrite in sphalerite are of common occurrence in many districts and have often been described.[78]

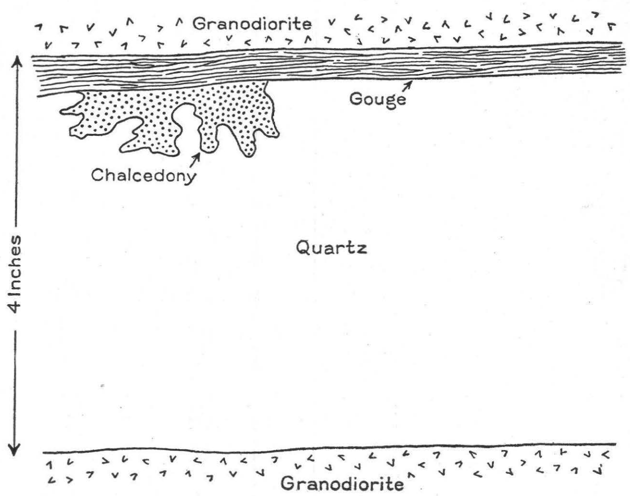


FIGURE 27.—Sketch of part of the Dromedary vein showing chalcedony in quartz. Golden Center mine, 500-foot level.

The uniform distribution, the isolation of each of the rods and dots, and the fact that the chalcopyrite content does not increase toward the margin of the host but tends rather to decrease point toward an origin by "exsolution" rather than by replacement of the sphalerite.

Buerger[79] found that in a 7-day run chalcopyrite unmixes from sphalerite at temperatures between 350° and 400° C. At higher temperatures chalcopyrite is dissolved in the sphalerite. As time is also a factor influencing this process, the temperature range obtained by Buerger cannot be applied to the Grass Valley ores.

CHLORITE

Chlorite (hydrous silicate of magnesium, iron, and aluminum) is widely distributed throughout the wall rocks of the district and is an abundant vein mineral.

In granodiorite and diabase it replaces augite (pl. 4, *D*), hornblende (pl. 5, *F*), and biotite. The replaced hornblende is most commonly uralite, which has itself been derived from primary hornblende or from augite. Such replacements by chlorite, while best developed adjacent to the veins, are also present in the freshest and least altered rocks remote from known vein fractures. The extent to which chloritic replacement was accomplished by solutions carried by the vein fractures is somewhat uncertain. Certainly some of the chloritization was brought about by the regional mechanism that caused the uralitization of the primary hornblende. It appears likewise certain that additional chloritization of the wall rocks adjoining the veins took place. Ferguson[80] has described a similar occurrence of chlorite at Alleghany and recognized a "chlorite stage" which preceded the "quartz stage" of vein filling.

In the veins chlorite is intimately intergrown with quartz, forming inclusions and partings between successive generations of quartz. It is also intimately intergrown with carbonates (pl. 16, *A*, *B*). In the vugs on the 6,300-foot level of the North Star mine, described on page 30, it occurs with carbonates cementing a mechanically ground mixture of quartz and early chlorite. A thin section of a specimen of vein material from the 5,000-foot level of the Empire mine (pl. 13, *B*) showed minute "worms" of chlorite 0.1 millimeter in length enclosed in both quartz and ankerite. Presumably they grew by replacement of the host.

Thus the deposition of chlorite appears to have extended through a considerable time range, beginning with the regional alteration of the rocks and extending through the quartz and carbonate substages of vein filling.

CHROMITE

A few grains of chromite ($FeO \cdot Cr_2O_3$) were observed in thin sections of serpentine from Grass Valley. Large, irregular, lenslike segregated masses in serpentine are common in the vicinity of Washington and they were noted in the Stocking Flat serpentine area, west of Nevada City. Although such large segregated masses were not observed in the Grass Valley quadrangle, it is probable that they also exist in the serpentine area. Chromite belongs to the magmatic stage of mineralization and is not present in the veins.

EPIDOTE

Epidote ($HCa_2(Al,Fe)_3Si_3O_{13}$) is widely distributed throughout the altered granodiorite and diabase wall rocks of the district. It was also observed lining a small cavity in a narrow aplite dike and coating pyrite in a quartz-lined vug in one of the veins.

It is most abundantly developed in wall rocks close to both vein and crossing fractures and is readily recognized by the unique pistacio-green color which it imparts to the rocks. In thin section such stained areas show a network of acicular epidote crystals replacing all the original rock minerals. Many weak and otherwise inconspicuous crossings are marked by such stains.

[78] Teas, L. P., The relation of sphalerite to other sulphides in ores: Am. Inst. Min. Eng. Trans., vol. 59, figs. 1 and 2, 1918. Van der Veen, R. W., Minerography and ore deposition, vol. 1, figs. 17–20, The Hague, 1925. Schneiderhöhn, H., and Ramdohr, Paul, Lehrbuch der Erzmikroskopie, vol. 2, pls. 42–45, Berlin, 1931. Schwartz, G. M., Textures due to unmixing of solid solutions: Econ. Geology, vol. 26, no. 7, fig. 14, p. 753, 1931. Shenon, P. J., Chalcopyrite and pyrrhotite inclusions in sphalerite: Am. Mineralogist, vol. 17, no. 11, pp. 514–518, 1932. Buerger, N. W., The unmixing of chalcopyrite from sphalerite: Am. Mineralogist, vol. 19, pp. 525–530, 1934.

[79] Buerger, N. W., op. cit., p. 530.

[80] Ferguson, H. G., and Gannett, R. W., Gold quartz veins of the Alleghany district, Calif., U. S. Geol. Survey Prof. Paper 172, pp. 38–40, 1932.

A small aplite dike, half an inch in width, exposed in the Chevanne shaft, contained a lenslike cavity a quarter of an inch wide and 1 inch long completely filled with epidote (fig. 5).

Epidote is not uncommon in vein material. In several thin sections of vein quartz narrow veinlets of epidote, either alone or with later quartz, were observed. One such veinlet is shown in plate 12, *C*. In the shaft of the Boundary mine, at the 300-foot level, a quartz vug 3 inches in diameter contained pyrite coated with minute epidote crystals.

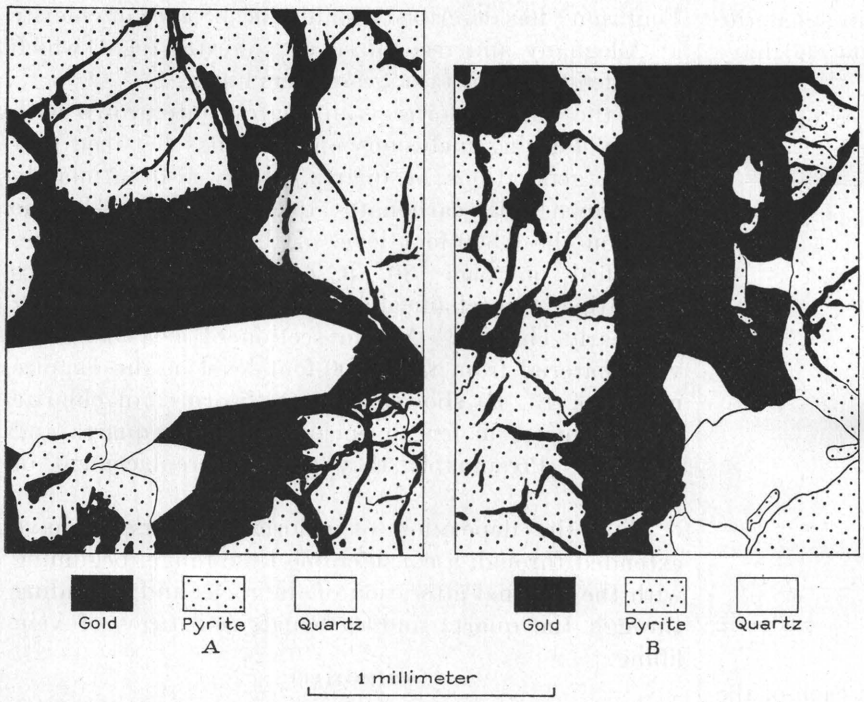


FIGURE 28.—Drawing of polished sections of vein material showing euhedral quartz crystals (white) occupying fractures in pyrite (stippled) that were later filled with gold (black).

The occurrences described suggest a long paragenetic range, extending, possibly, from the end of the injection of aplites well into the quartz substage of vein filling.

GALENA

Through the district galena (PbS) is regarded as a favorable indication of gold. With sphalerite and chalcopyrite, it was deposited later than the vein pyrite, which it commonly replaced. In several specimens gold and galena occur together in cracks in the pyrite. The distribution and mutual relations of these two minerals suggest that they are contemporaneous. Less commonly galena is found in quartz remote from other sulphides.

GOLD

Gold is widely but erratically distributed in the quartz veins of the district. Most of it is intimately associated with pyrite and other sulphides. A smaller proportion occurs in quartz that is entirely free from sulphides, and more rarely it occurs in calcite.

Gold is later than the vein pyrite, arsenopyrite, and some of the sphalerite, and it replaces these minerals along minute fractures (pl. 14, *A*, *B*). It shows no preference in replacement, its constant association with pyrite being due to the dominance of that mineral in the veins. Many pyrite crystals when removed from the quartz that embeds them leave a striated mold lined by a thin leaf of gold which was deposited in contact with the pyrite.

Little can be determined regarding the age relations of gold and galena. Both fill fractures and cavities in the older sulphides, and frequently both occur in the same cavity, where gold surrounded by galena and galena surrounded by gold have been observed. The preponderance of evidence indicates that they were deposited together.

Where gold occurs in tight quartz veins poor in sulphides it shows a preference for that part of the vein which has undergone microbrecciation (pl. 13, *A*). In veins retaining some primary cavities, it has been deposited on quartz crystals lining the vugs (fig. 28).

That its deposition overlapped the deposition of carbonates was shown in specimens from the 8,700-foot level of the North Star mine, where gold is surrounded and supported by calcite. A specimen from the Alcalde mine, 4 miles southwest of Grass Valley, loaned to me by Mr. Nobs, contained coarse leaf gold penetrating cleavage planes in calcite.

While most of the gold is intimately associated with sulphides and is recovered by cyaniding the vein concentrates, coarse or "specimen" gold is by no means rare and is the source of a constant loss to the companies by "high grading."

The average fineness of the gold bullion of the district ranges between 0.800 and 0.855, although bullion from the cyanide mills is sometimes lower. Exceptional bullion may reach 0.900 fine or drop to 0.700.

Four specimens of gold with different mineral associations were selected for analysis. The gold was sorted as cleanly as possible under a binocular microscope and analyzed in the chemical laboratory of the Geological Survey by fire assay, cupellation, and parting. The surprisingly uniform fineness of the four samples clearly indicates that the gold-silver ratio is independent of the associated sulphides.

Fineness of gold from Grass Valley

[E. T. Erickson, analyst]

Locality	Description	Au	Ag	Undetermined [1]	Au/Au+Ag ratio
Pennsylvania, 1,400 level	Gold in sheared quartz, no sulphides	82. 34	11. 54	6. 12	0. 877
Empire, 5,400 level, south	Gold from cracks in pyrite crystal	85. 86	12. 50	1. 64	. 873
North Star 9,000 level	Gold in contact with pyrite and galena	84. 37	11. 56	4. 07	. 879
Empire, 3,400 level, north	Gold in comb quartz, no sulphides	85. 48	11. 82	2. 70	. 877

[1] By difference. This represents quartz and sulphides from which the gold could not be completely sorted.

GYPSUM

Gypsum ($CaSO_4.2H_2O$) is a supergene mineral formed by the action of sulphuric acid, freed from pyrite by oxidation, upon the calcite and ankerite of the veins and the wall rocks. It was not recognized as a primary vein mineral.

Fine, needlelike gypsum crystals showing fishtail terminations occur on the walls of abandoned workings. On the 1,500-foot west level of the North Star mine behind a low dam formed of fallen rock, the floor of the drift was covered to a depth of 10 inches by a soft, milky paste composed of fine-grained gypsum crystals suspended in water. This gypsum paste came down into the drift from one of the stopes.

HEMATITE

In several of the veins and crossings dark, earthy hematite (Fe_2O_3) was observed in association with carbonates. On the 9,000-foot level of the North Star mine small, irregular hematite aggregates 1 to 5 millimeters in diameter are contained in a fine-grained, clouded carbonate vein-filling which had been partly replaced by clear calcite. On the 1,400-foot level of the Pennsylvania mine ankerite containing hematite inclusions fills a crossing fracture. From these observations the hematite appears to have been deposited during the carbonate substage, subsequent to the deposition of the greater part of the vein quartz.

Blades and rosettes of specularite embedded in a groundmass of chlorite and probably later carbonates (pl. 12, *D*) fill a strong crossing fracture which is intersected by the north drift on the 4,600-foot level of the Empire mine. The crossing filling also contains a small amount of pyrite. Specularite, which was nowhere else observed, is probably earlier than the vein minerals and, with the pyrrhotite and magnetite of the Crown Point vein, belongs to a high-temperature stage of mineralization.

LIMONITE

Limonite, or more properly ferric hydrate ($Fe(OH)_3$), is formed by the oxidation of iron-bearing waters in the upper workings of most of the mines of the district. In abandoned drifts it coats the walls, forms stalactites and stalagmites, and covers the drift floors with a pasty emulsion. It is most abundant in broken ground where open crossing fractures permit the descent of much water. The iron is derived mainly from pyrite, which impregnates the diabase and granodiorite vein walls.

MAGNETITE

Magnetite ($FeO.Fe_2O_3$) is a primary accessory constituent of some of the diabase rocks of the district and is abundant in serpentine. It is a rare vein mineral, having been observed only in the Crown Point vein, where it occurs in association with pyrrhotite and pyrite.

Lindgren [81] records a small deposit of magnetite "in the diabase, near the granodiorite contact, 4,000 feet east of the Omaha mine, in Diamond Creek."

MARIPOSITE

Specimens of vein quartz from the Coe and Eureka mine dumps contain apple-green mariposite (chrome mica), which can be identified by its green color, faint pleochroism, high birefringence, and micaceous habit Much sericite is present in the specimens, and the mariposite, though imparting a green color to the rock, constitutes only about 3 percent of the micaceous minerals. Mariposite is confined to the areas of serpentine in the northern part of the quadrangles. McBoyle [82] states that the dolomitized serpentine forming the footwall of the Idaho-Maryland vein is in places colored green by this mineral. The association of mariposite with serpentine at Grass Valley is similar to that on the Mother Lode described by Knopf,[83] and at Alleghany described by Ferguson.[84]

MOLYBDENITE

Although molybdenite (MoS_2) is found in many of the mines of the Nevada City district, I did not recognize it at Grass Valley. Fred Nobs,[85] however, reports its sparse occurrence in the Empire mine.

PYRITE

Pyrite (FeS_2) is the most abundant metallic mineral in the veins, as well as the oldest sulphide. Broken cubes and pyritohedrons are embedded in the earliest quartz in the veins. Later quartz generally contains less pyrite.

Adjoining the veins diabase and, to a lesser extent, granodiorite wall rocks contain much pyrite of hydrothermal origin in the form of small cubes replacing any or all of the original minerals of the rock.

[81] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 120.

[82] McBoyle, Errol, Mines and mineral resources of Nevada County, p. 188, California State Mining Bureau, 1918.

[83] Knopf, Adolph, The Mother Lode system of California: U. S. Geol. Survey, Prof. Paper 157, p. 38, 1929.

[84] Ferguson, H. G., and Gannett, R. W., Gold quartz veins of the Alleghany district, California: U. S. Geol. Survey Prof. Paper 172, pp. 46–47, 1932.

[85] Oral communication.

The greater part of the pyrite is earlier or contemporaneous with the earliest of the vein quartz, but a small amount was deposited late in the process of vein filling. Such later pyrite was observed filling shear fissures in the vein quartz (fig. 29), and occupying cleavages in calcite (pl. 12, *E*).

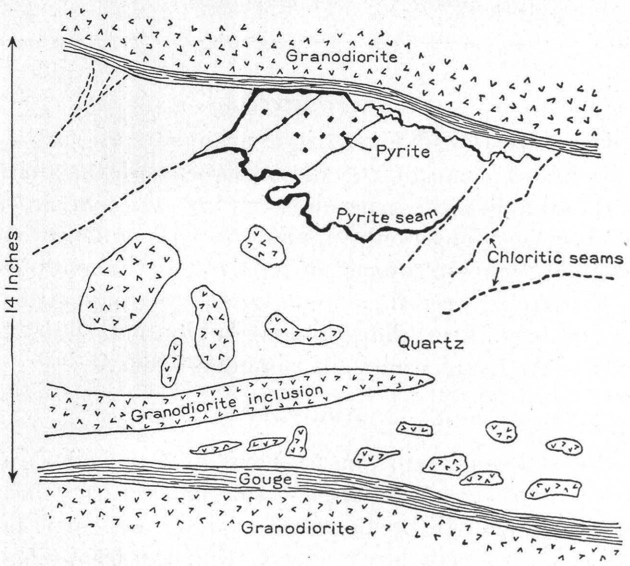


FIGURE 29.—Sketch of vein showing late pyrite and chlorite occupying seams in quartz. Newmont vein, 3,800-foot level, Empire mine.

Some pyrite appears to be a primary accessory constituent of the diabase. It is also associated with specularite, magnetite, and pyrrhotite in those vein and crossing fillings which are here assigned to the hypothermal stage of mineralization.

Thus pyrite is a mineral which was formed over a wide range of temperature and pressure conditions and whose peak of deposition came in the early stages of vein filling. It is earlier than any of the other sulphides, with the possible exception of arsenopyrite. With the other sulphides it furnished sites for the deposition of gold.

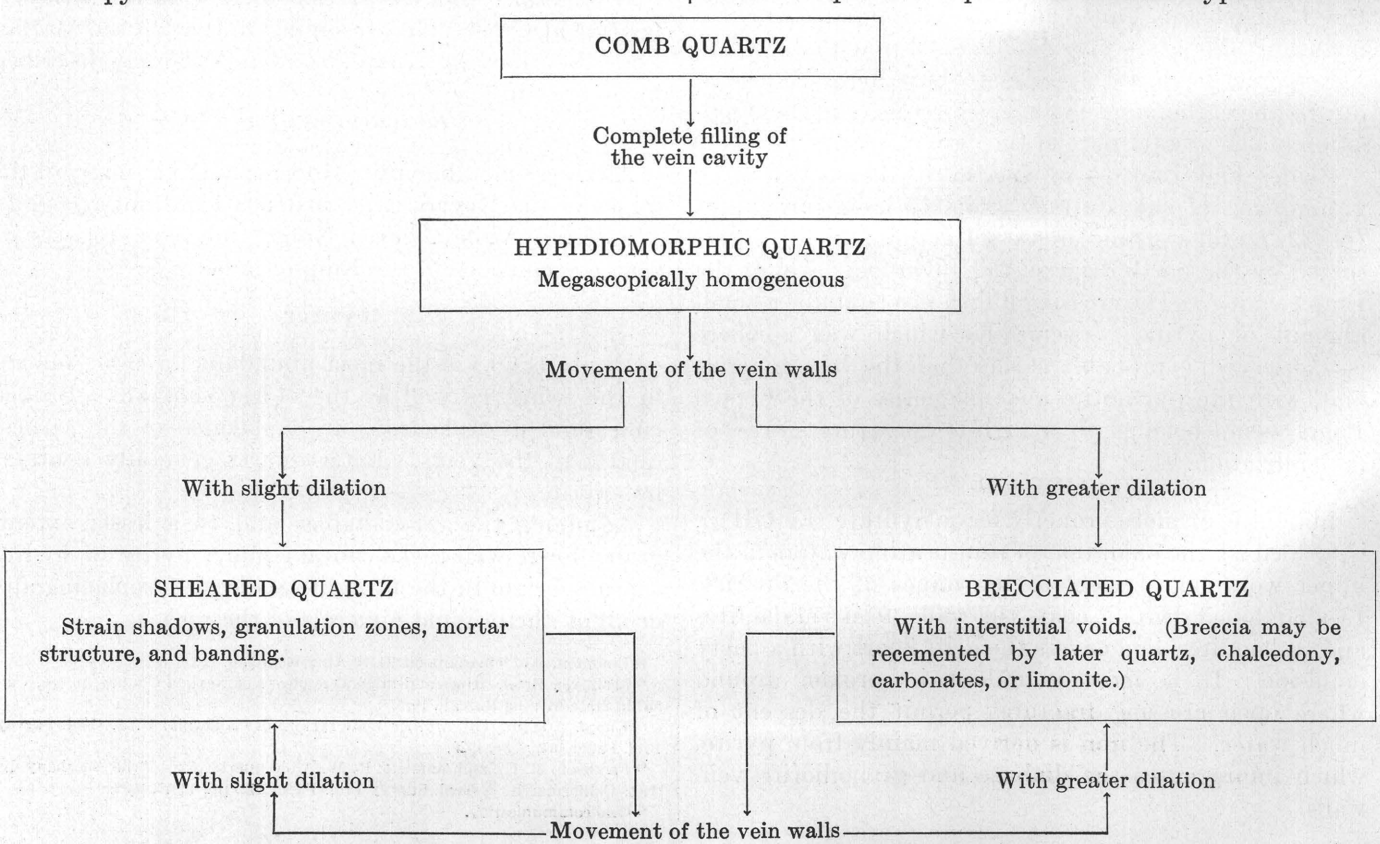
PYRRHOTITE

Pyrrhotite (Fe_nS_{n+1}) is a primary accessory constituent of some of the diabases of the district and occurs as a secondary hydrothermal mineral in several rocks. It occurs with magnetite and pyrite in the Crown Point vein, which is cut by the 4,200-foot level crosscut at the north end of the Empire mine, and the mineral was obtained in the Crown Point mine dump. It was not recognized in any other veins of the district. With specularite and magnetite it belongs to the first stage of high-temperature mineralization.

QUARTZ

Quartz (SiO_2) is the principal vein mineral of the district. It is preponderently milky white and translucent and has a vitreous to greasy luster. Less commonly it is semitransparent or darkened by included material.

In hand specimens four general types of quartz texture are readily recognized. They are (1) comb quartz, (2) massive milky hypidiomorphic quartz, commonly called "bull quartz," (3) sheared quartz, and (4) brecciated quartz. In addition to these four distinct types, intermediate varieties and combinations of the various types are of common occurrence. New vein material may be introduced at any stage. The following diagram is an attempt to show the genetic relationship of vein quartz of the four types:



Individual quartz crystals from vugs show long prisms terminated by unequally developed rhombohedrons, and trigonal trapezohedral faces, characteristic of low-temperature quartz, were observed on approximately 5 percent of the crystals examined.

Comb quartz.—Although comb quartz constitutes less than 1 percent of the total vein quartz, it is widely distributed throughout the district and is as abundant in the deeper levels as it is near the surface. Vugs lined with terminated crystals are usually small, and the individual crystals rarely exceed 1 inch in length. Exceptionally large vugs, 1 foot in width and 3 feet in length, with crystals as much as 4 inches long, were cut on the 6,300-foot level, No. 2 vein of the North Star Mine (pl. 15, *A*), and Lindgren[86] remarked one vein cavity in the Rose mine "2 or 3 feet in diameter."

Comb structures whose individual crystals are normal to the vein walls and only partly fill the vein cavity (pl. 17) are more common than rounded vugs. Such comb structures are conspicuous only where the quartz crystals either fail to fill the cavity completely or are coated by carbonates and so preserve the structure. Plate 18, *A* and *B*, shows opposite sawcuts of a narrow portion of the No. 2 vein, 8,600-foot level, North Star mine. *A* shows the polished face of the vein composed of quartz and carbonates. *B* is the opposite sawcut face, which has been immersed in hydrochloric acid until all the carbonates were dissolved. The remaining quartz shows a typical comb structure formed by crystals growing freely in an open cavity.

Dense milky-white homogeneous quartz.—Much more continuous than comb quartz is the dense milky-white, megascopically homogeneous quartz. It is abundant in all the veins of the district. Commonly it fills smaller fissures, but it may attain a width of several feet in places where there has been little or no post-quartz movement of the vein walls (pl. 8, *A*). Such quartz has a greasy to vitreous luster, is translucent, and has a distinctive milky-white color. In hand specimens and in underground exposures it appears to be essentially homogeneous, in contrast with comb quartz or the sheared and brecciated types.

In thin section, under low magnification, this type of quartz is generally hypidiomorphic, composed of interlocking euhedral to subhedral crystals. Rectilinear crystal boundaries are abundant, and well-developed basal sections are common. Thin sections from the edge of the vein cut parallel to the vein walls show many basal sections of quartz with interstitial subhedral to anhedral quartz crystals having random orientation. The structure of such sections is identical with that of sections cut from comb quartz embedded in calcite, except for the character of the unoriented matrix. Sections from the center of the veins characteristically show subhedral to anhedral interlocking crystals.

Numerous underground exposures (pl. 9, *A*, *B*), as well as microscopic evidence, compel acceptance of the interpretation that comb quartz and homogeneous milky quartz grade into each other. Thus the partial filling of a cavity results in comb quartz, and the complete filling gives the megascopically homogeneous milky quartz. Later movement of the vein walls has transformed most of the original homogeneous quartz into sheared and brecciated types.

Sheared quartz.—Abundant strain shadows, mortar structures, and granulation zones bear witness to the fact that much of the quartz of the district has been mechanically deformed subsequent to its deposition in the veins.

Strain shadows (pl. 7, *C*) are the first of the shear phenomena to be developed. Under the microscope they show considerable variation, ranging from irregular areas or broad bands with transitional extinction to closely spaced light and dark bands suggesting the polysynthetic twinning of plagioclase. In places the latter variety is further complicated by the presence of two or more intersecting systems of "twinning" bands, giving the quartz a reticulated pattern. In several thin sections the strain shadows were best developed along the borders of crystals, suggesting the mechanism for the development of mortar structures by the breaking down and final granulation of the peripheries of the crystals. A characteristic mortar structure is shown in plate 19, *C*.

More common than mortar structures are irregular granulation zones cutting across both large and small quartz crystals (pl. 19, *B*). The individual quartz grains in the granulation zones range approximately between 0.01 and 0.1 millimeter in diameter, and the width of the zones ranges between 0.2 and 2.0 millimeters. More rarely the granulation zones are wider, more regular, and more persistent and can be described as mylonitic zones (pl. 19, *A*). Most of those observed were adjacent and parallel to one of the vein walls, but others trend diagonally across the vein and apparently served as major adjustment zones for relieving differential stresses on the vein walls.

Few underground exposures of wide veins are free from the above-described shear structures, produced by movement of the vein walls resulting in little or no dilation of the vein cavity. In contrast with these shear structures are the vein breccias with interstitial spaces produced by dilational movement of the vein walls resulting in an increase in available space. Such structures are described in the following paragraphs.

Brecciated quartz.—Vein breccias, though not as abundant as the shear structures, are present in all the veins examined, and commonly both structural types are present in the same underground exposure. Brecciated quartz differs from sheared quartz in the presence of

[86] Lindgren, Waldemar, discussion of Howe's paper in Econ. Geology, vol. 29, 320, 1924.

interstitial spaces between the breccia fragments, although these spaces have usually been filled by later vein material.

There is considerable range of size in the breccia fragments. Plate 8, *F*, shows a vein 6 inches wide in which the average diameter of the breccia fragments is 2 inches, and plate 13, *E*, shows a microbrecciation zone 0.3 millimeter wide in which the average diameter of the fragments is 0.05 millimeter.

All the observed vein breccias were recemented, usually by quartz or carbonates. Plate 20 shows photomicrographs of three types of breccias. In *A* the cementing material is ankerite, in *B* it is clear chalcedony, and in *C* it is limonite-bearing chalcedony. *C* also shows an older generation of granulation by shearing, which preceded brecciation. Many thin sections of vein material show angular quartz fragments cemented in a matrix of quartz of slightly different appearance, usually clearer than the earlier generation. Some of these may be breccias in which interstitial cavities at one time existed but have since been cemented by clear quartz. Similar breccias from the Alleghany district are figured by Ferguson and Gannett.[87] They, however, included under their term "microbreccia" what I describe as (1) sheared quartz which has undergone but little dilation and (2) brecciated quartz which has developed interstitial spaces between the breccia fragments. I restrict the term "microbreccia" to fine-grained varieties of the latter class.

Inclusions and vacuoles.—Quartz in thin sections under low magnifications has a cloudy appearance, as if speckled with grains of dust (pls. 20, *A*, 17, *B*, 21, *A*, *B*, *C*, 16, *A*, *B*). With higher magnifications (300+) the dustlike particles are resolved into (1) solid inclusions of undetermined composition and (2) liquid-filled inclusions, most of which also contain a gas bubble (pl. 22). As the solid inclusions have a maximum diameter of 0.001± millimeter, their composition could not be determined with certainty. However, their irregular habit and dull appearance suggest that they may be clay minerals.

The liquid-filled vacuoles range between 0.06 and 0.0001 millimeter in diameter, and generally the larger quartz crystals contain the larger vacuoles. Two types of cavities were recognized—(1) negative crystals with rather sharply defined faces and (2) irregular vacuoles with rounded walls, frequently having elongated apophyses extending out from the main cavity.

The gas bubbles occupy from one-twentieth to one-fifth of the volume of the vacuoles, and there appears to be no relation between the angularity of the vacuoles and the relative size of the bubble. In examining some of the smaller vacuoles under a magnification of 500 with the tube of the microscope in a horizontal position, it was observed that, upon rotation of the stage, the gas bubble rose very slowly through the liquid, much as an air bubble might rise in glycerine or other viscous medium. Ferguson[88] had noted similar behavior of gas bubbles in vein quartz from the Alleghany district, California. Thicker sections of Grass Valley quartz cut from large individual crystals contain vacuoles as much as 0.06 millimeter in diameter. In some of these larger vacuoles the bubbles are fixed, possibly by constrictions in the cavities; others show considerable variation in the rate of movement of the bubble through the liquid under the influence of gravity.

In order to determine the chemical character of the occluded liquid Lindgren[89] submitted a sample of picked quartz from the Providence mine, Nevada City, to the chemical laboratory of the Geological Survey. He describes the tests made there as follows:

> Five hundred grains of the powdered rock was treated with cold water for 2 days; then heated 3 hours on the water bath and filtered. This gave a milky filtrate which amounted to about 1,000 cubic centimeters. The filtrate was evaporated to 50 cubic centimeters and filtered again. This filtrate was perfectly clear, and its analysis is marked B. The residue on the filter was examined separately, its analysis being marked A. This residue contained some carbonates which had evidently been in solution.

Analyses of quartz containing inclusions

[George Steiger, analyst. Grams per ton of quartz]

	A	B	C
SiO_2	3	28	124
Al_2O_3, Fe_2O_3	2	2	10
CaO	13	44	8
MgO	--------	1	--------
$(K,Na)_2O$	--------	29	23
SO_3	--------	78	20
Cl	--------	5	--------
	18	187	185

Lindgren concludes: "In all probability the soluble salts were contained in the fluid inclusions."

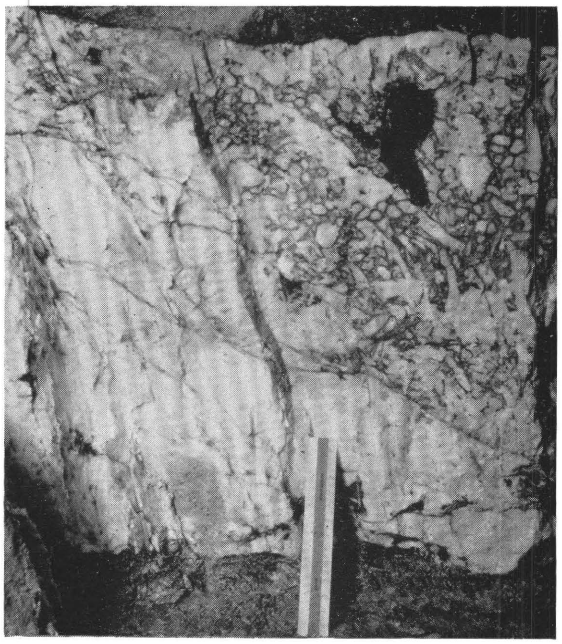
In 1933 George Steiger repeated the experiment on a quartz specimen from the 8,600-foot level of the North Star mine that contained unusually large inclusions. His results are shown in column C of the table. Although almost five times as much SiO_2 was obtained as was yielded by the specimen analyzed in 1896, Mr. Steiger doubted that it had all been in solution in the vacuole liquid. He was of the opinion that fine grinding, such as was necessary to break the vacuoles, might have facilitated solution of some of the vein quartz during leaching.

The fluid inclusions show two general types of arrangement—(1) in parallel planes determined by the crystallographic directions of the occluding crystal, giving zonal "growth lines" (pl. 21, *B*, *C*) and (2) in roughly parallel planes which are more or less independent of crystallographic directions and extend across adjacent crystals. Those of the first type are undoubtedly primary in-

[87] Ferguson, H. G., and Gannett, R. W., Gold quartz veins of the Alleghany district, Calif.: U. S. Geol. Survey Prof. Paper 172, pl. 14, *A*, *B*.

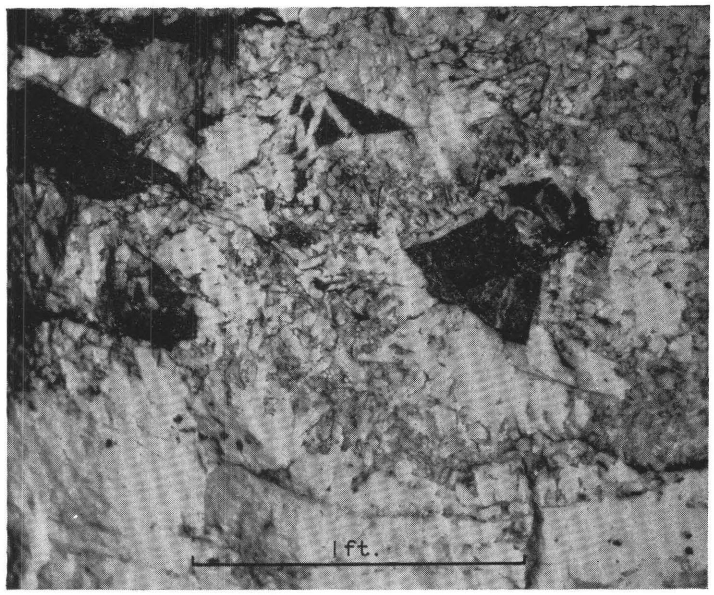
[88] Ferguson, H. G., Lode deposits of the Alleghany district, Calif., U. S. Geol. Survey Bull. 580, p. 161, 1915.

[89] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), pp. 130-131.



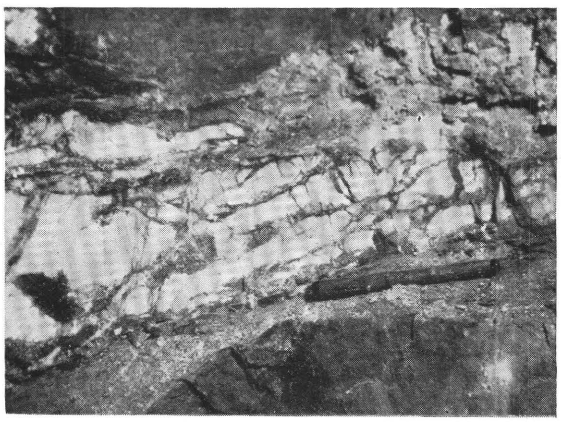
A. VEIN SHOWING THE TRANSITION BETWEEN DENSE MILKY HOMOGENEOUS QUARTZ AND COMB QUARTZ.

The dark rims around the combs are carbonates. North Star mine, No. 2 vein, 6,900-foot level. The scale is 6 inches long.



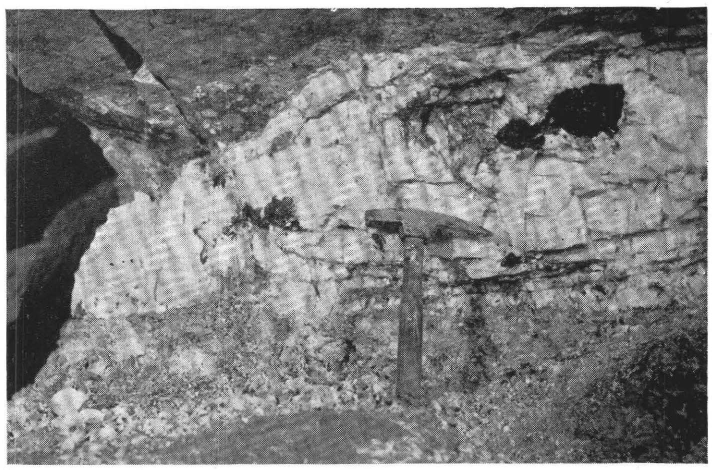
B. ANGULAR INCLUSIONS SURROUNDED BY COMB QUARTZ.

North Star mine, No. 2 vein, 6,600-foot level.



C. BRECCIATED VEIN FILLING.

North Star mine, A vein, 4,000-foot level.

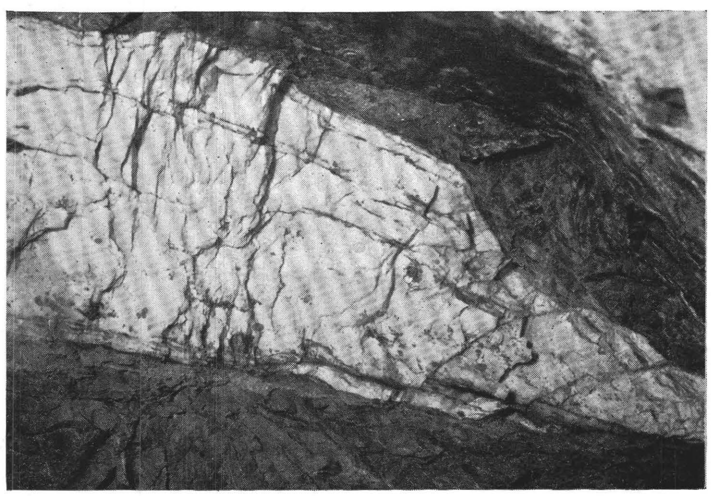


D. LARGE PYRITE MASSES (BLACK) IN SHEARED QUARTZ.

North Star mine, No. 2 vein, 6,600-foot level.

E. SHEARED QUARTZ VEIN WITH FEW SULPHIDES.

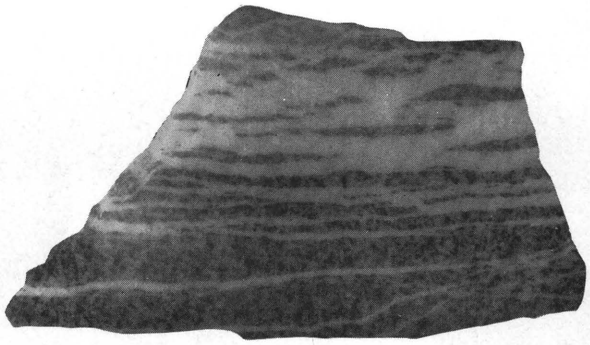
North Star mine, No. 1 vein, 6,600-foot level.



F. PINCH IN QUARTZ VEIN FROM 24 TO 6 INCHES.

North Star mine, No. 2 vein, 7,200-foot level.

UNDERGROUND PHOTOGRAPHS OF QUARTZ VEINS.

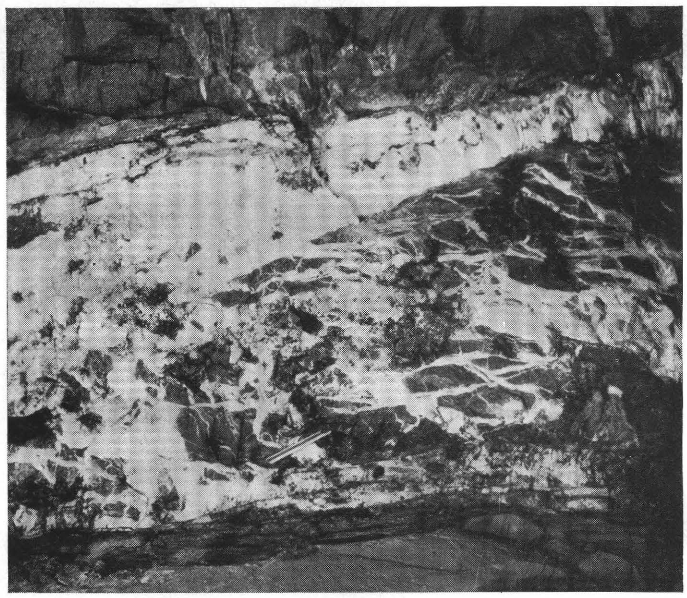


A. POLISHED SLAB OF GRANODIORITE SHOWING SHEETED ZONE OF CARBONATE VEINLETS.

North Star mine, No. 1 vein, 7,200-foot level.

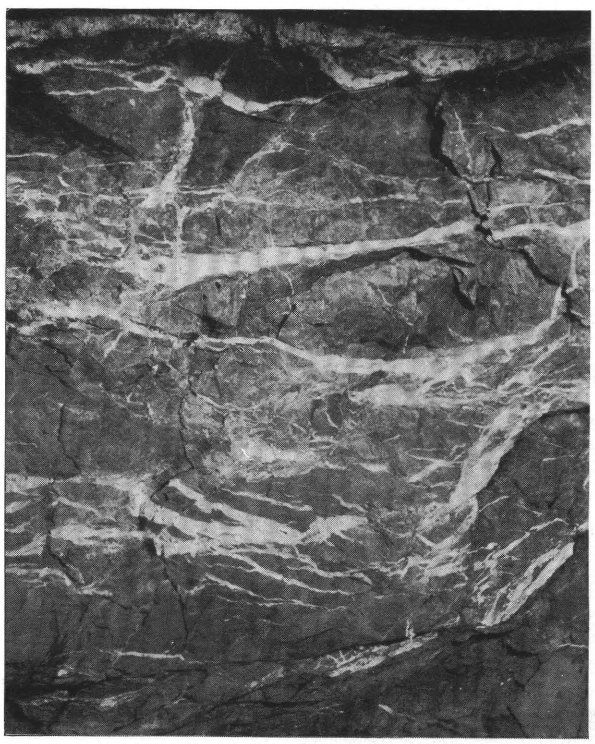
B. SHEETED VEIN.

North Star mine, No. 3 vein, 8,600-foot level.



C. SPLIT IN QUARTZ VEIN WITH BADLY SHATTERED SEPTUM AND MANY CROSS VEINLETS.

The granodiorite inclusions are probably replaced by carbonates and sericite. The scale is 6 inches long. North Star mine, No. 2 vein, 6,600-foot level.



D. SHEETED ZONE AT INTERSECTION OF TWO VEINS.

North Star mine, No. 2 drift, 8,200-foot level.

E. FLAT VEIN WITH FOOTWALL STRINGERS.

North Star mine, New York Hill vein, 600-foot level.

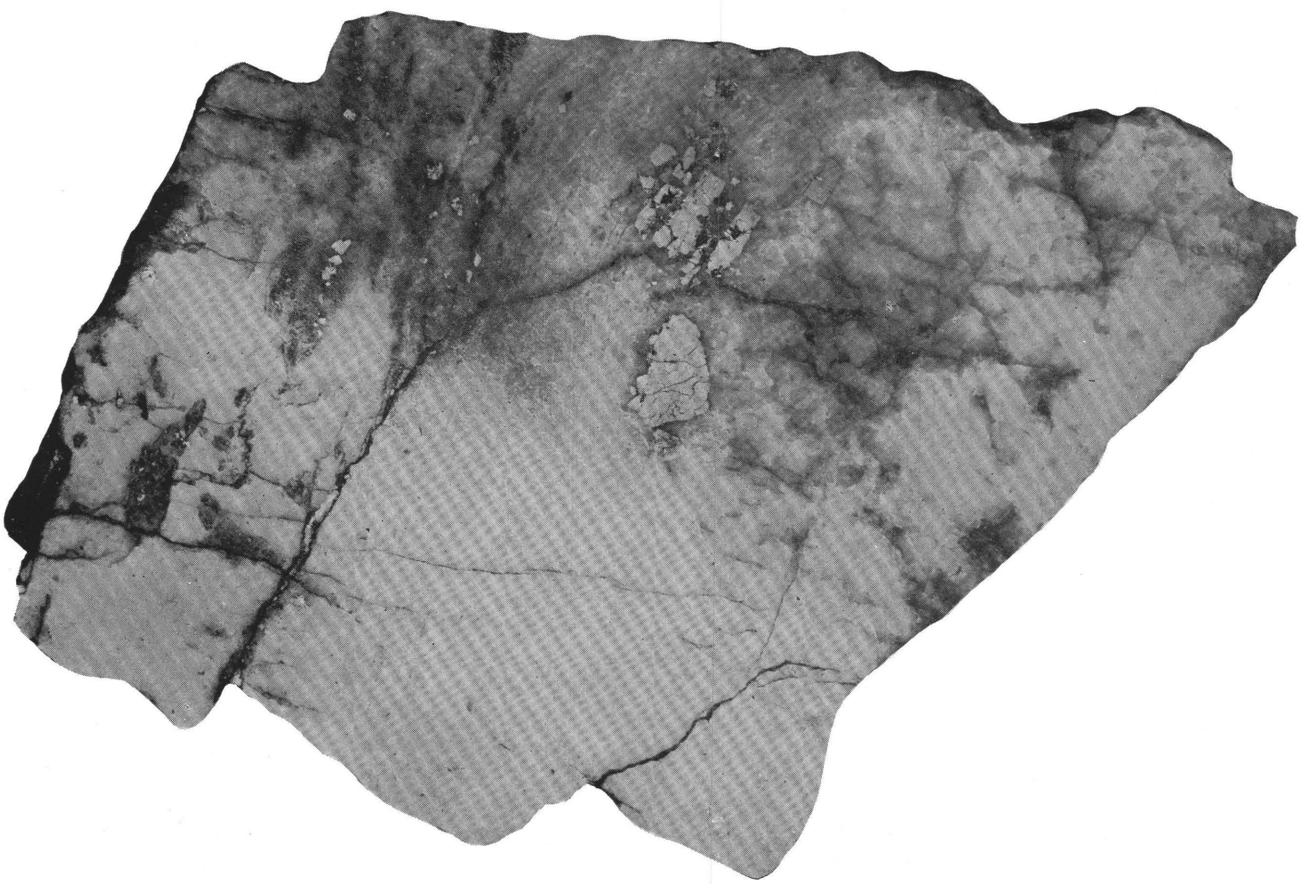
UNDERGROUND PHOTOGRAPHS OF SHEETED VEINS.

A. POLISHED SLAB SHOWING BROKEN PYRITE IN VEIN QUARTZ.

North Star mine, No. 1 vein, 8,200-foot level.

B. POLISHED SLAB SHOWING SHEARED QUARTZ WITH LATER CALCITE

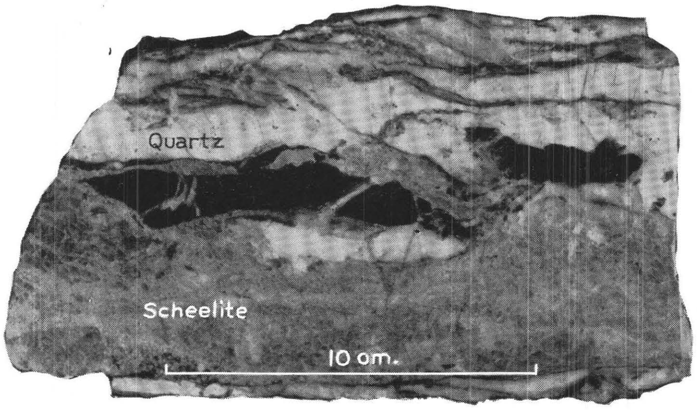
The black areas are indurated gouge. North Star mine, New York Hill vein, 3,400-foot level.



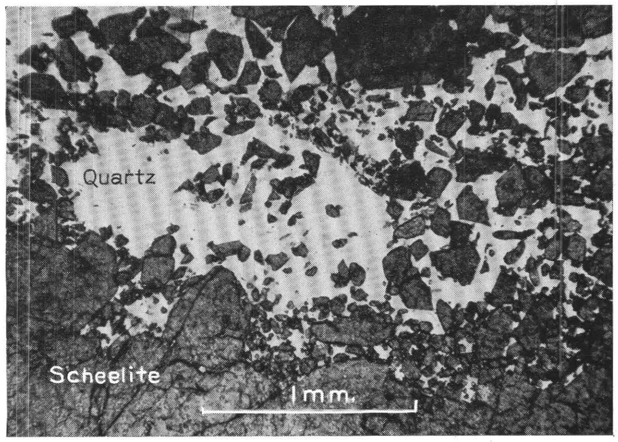
C. POLISHED SLAB SHOWING SHEARED QUARTZ WITH CARBONATE CEMENT.

North Star mine, No. 3 vein, 9,000-foot level.

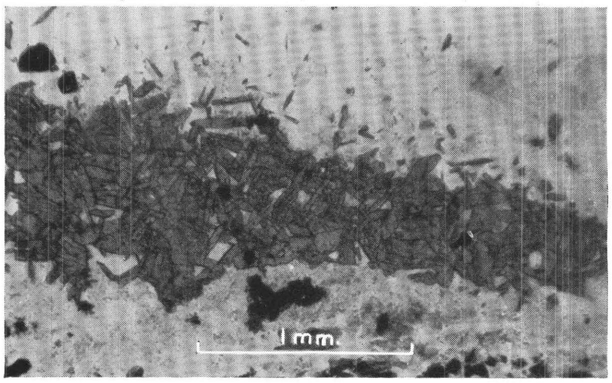
PHOTOGRAPHS_OF ORE.



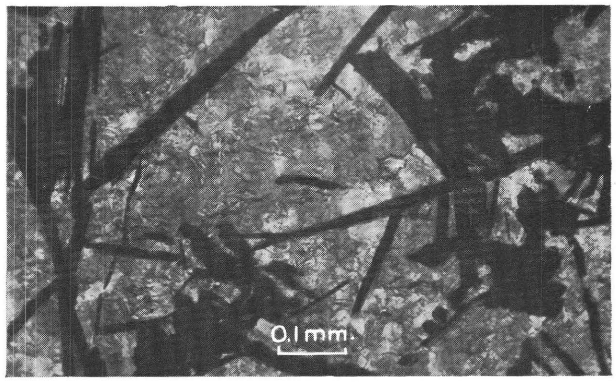
A. POLISHED SLAB SHOWING SCHEELITE AND QUARTZ VEIN FILLING.
Union Hill mine.



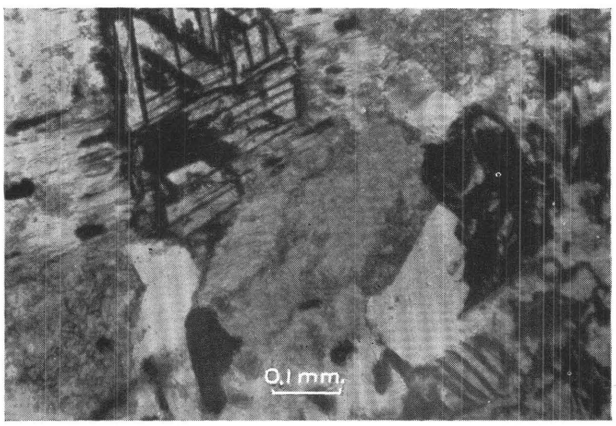
B. THIN SECTION SHOWING DETAIL OF *A*.
The scheelite (dark) is fractured and cemented by quartz (light).



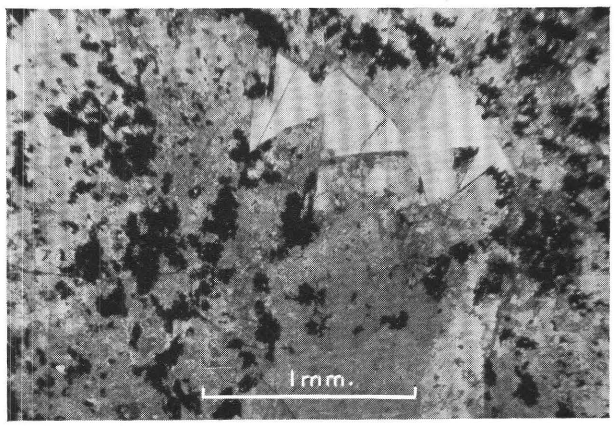
C. EPIDOTE IN QUARTZ VEIN FILLING.
Boundary mine.



D. SPECULARITE FOILS IN CHLORITE MATRIX OF CROSSING FILLING.
Empire mine, 4,600-foot level.

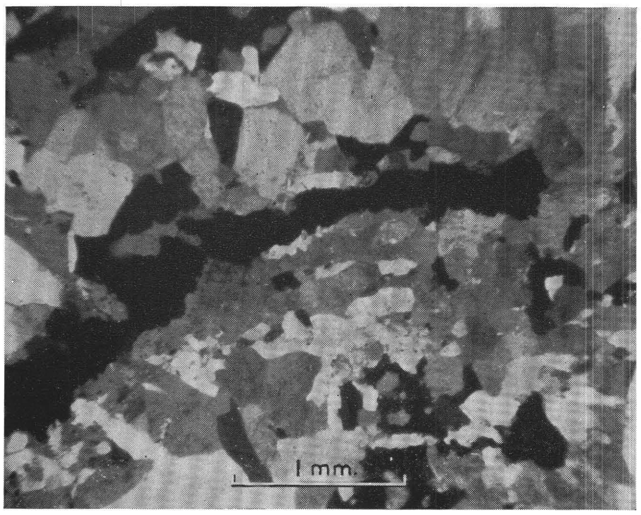


E. LATE PYRITE DEPOSITED ON CLEAVAGE PLANE IN CALCITE.
North Star mine, No. 3 vein, 9,000-foot level.



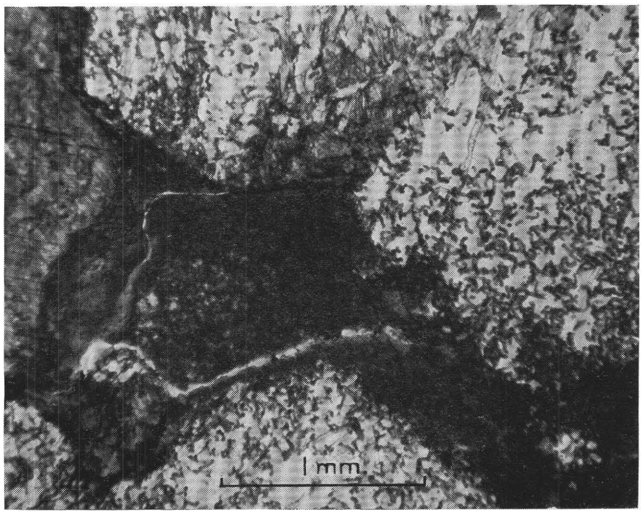
F. HEMATITE (BLACK) IN ANKERITE WITH EUHEDRAL CALCITE REPLACING THE ANKERITE.
North Star mine, No. 3 vein, 9,000-foot level.

MINERALOGY OF THE VEINS.



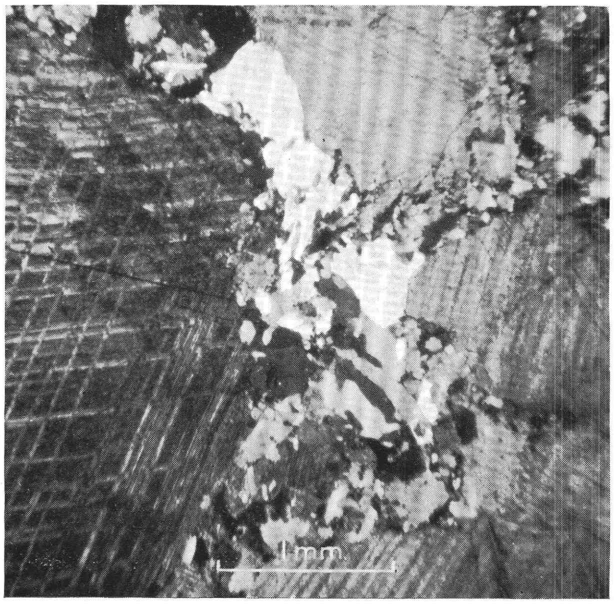
A. GOLD (BLACK) IN SHEARED QUARTZ.

Empire mine, 1,100-foot level. Nicols at 85°.



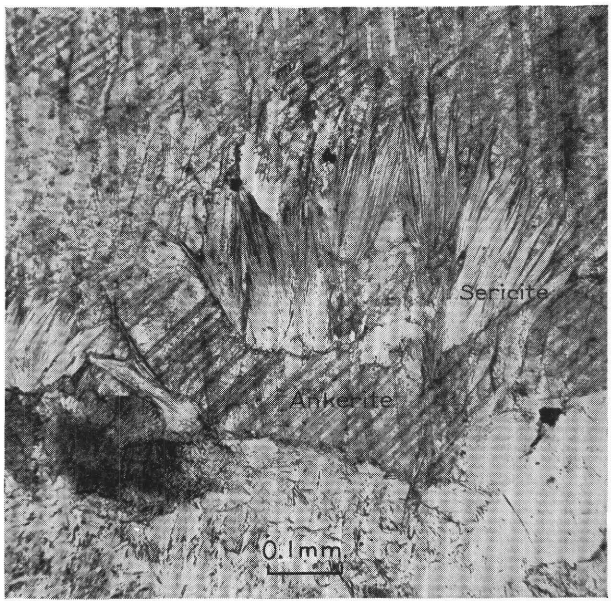
B. CHLORITE "WORMS" REPLACING QUARTZ AND ANKERITE.

The dark area in the center is mainly chlorite. Empire mine, 5,000-foot level. One nicol.



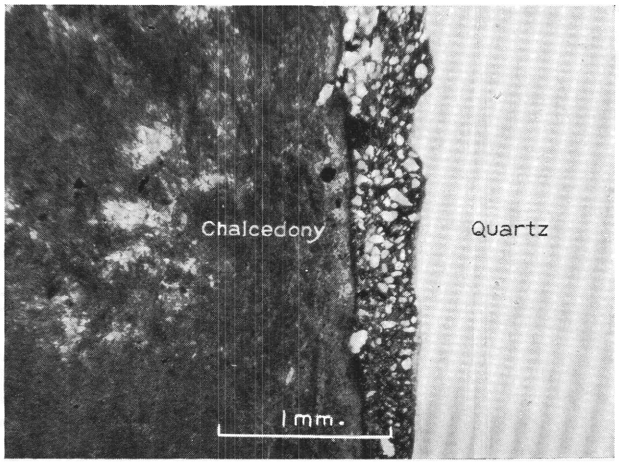
C. LATE INTERSTITIAL QUARTZ IN ANKERITE VEIN FILLING.

New York Hill mine, drain-tunnel level. Crossed nicols.



D. SERICITE REPLACING ANKERITE.

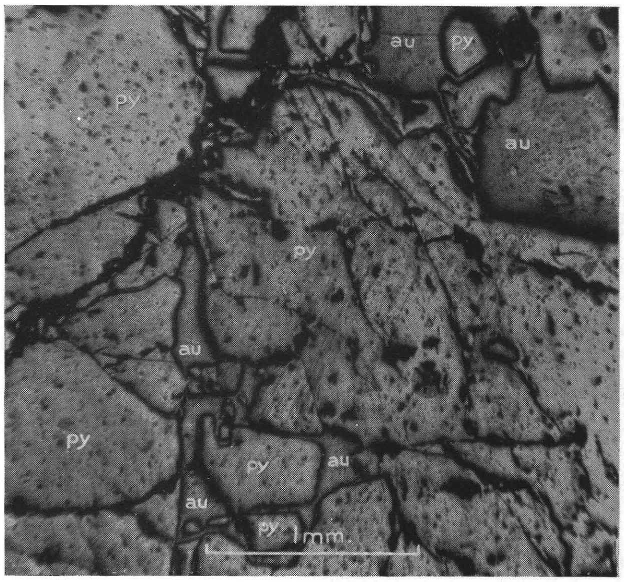
Golden Center mine, 500-foot level. Plain light.



E. MICROBRECCIATION BETWEEN CHALCEDONY AND QUARTZ.

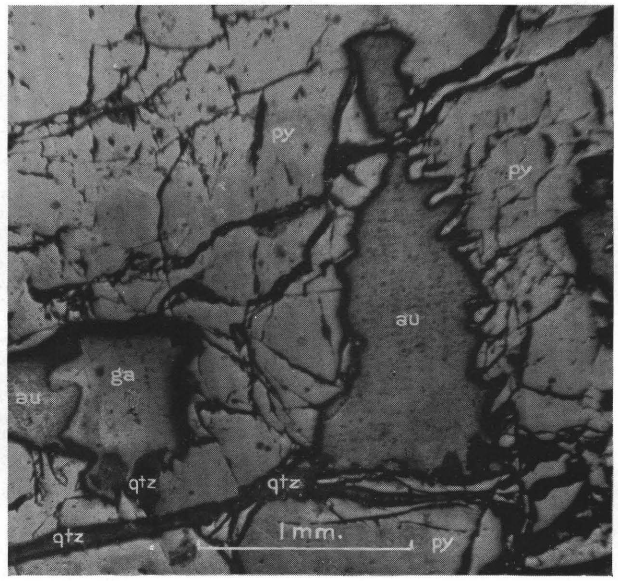
The cementing material is chalcedony. Old North Star dump. Plain light.

MINERALOGY OF THE VEINS.



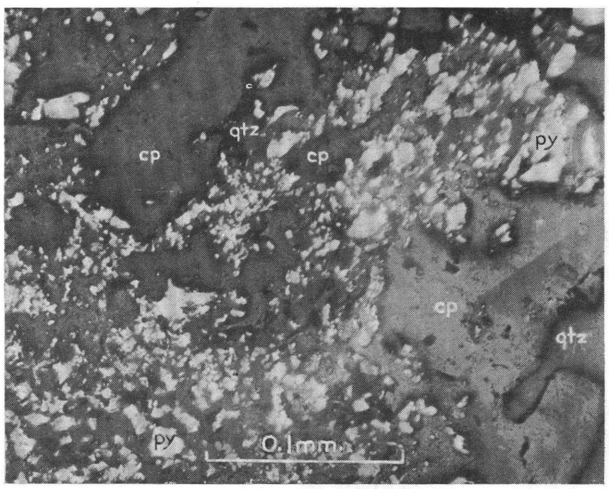
A. GOLD FILLING CRACKS IN FRACTURED PYRITE.

North Star mine, No. 3 vein, 9,000-foot level.



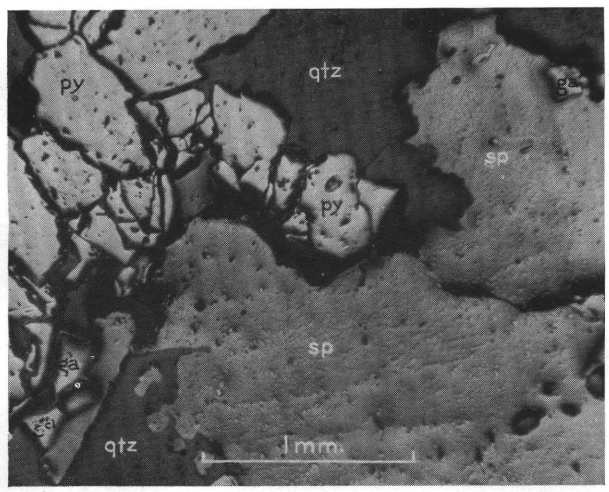
B. GOLD AND GALENA REPLACING PYRITE.

Empire mine, 5,400-foot level.



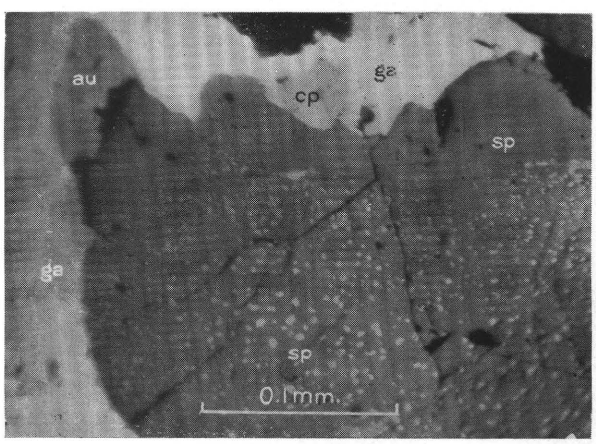
C. CHALCOPYRITE REPLACING FINE GRANULAR PYRITE ALONG SHEAR ZONE.

Empire mine, 3,000-foot level.



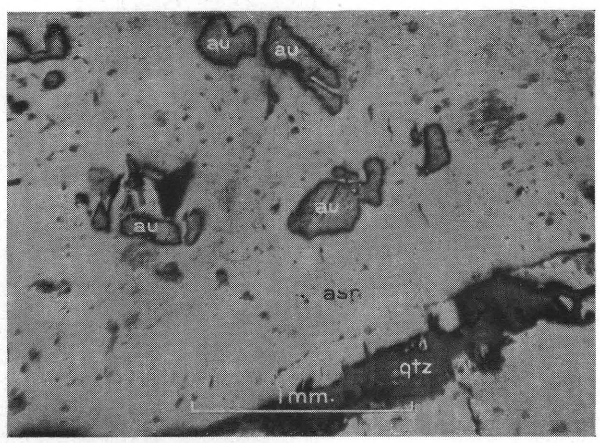
D. SPHALERITE REPLACING QUARTZ.

Note corroded quartz crystal in lower left corner. The sphalerite contains lines of chalcopyrite inclusions. North Star mine, 4,000-foot level.



E. SPHALERITE WITH CHALCOPYRITE INCLUSIONS, GALENA, GOLD, AND CHALCOPYRITE.

North Star mine, 4,000-foot level.



F. ARSENOPYRITE CONTAINING BLEBS OF GOLD AND CUT BY SMALL QUARTZ VEIN.

Empire mine, 1,300-foot level.

PHOTOMICROGRAPHS OF POLISHED ORE.

Au, gold; py, pyrite; ga, galena; qtz, quartz; cp, chalcopyrite; sp, sphalerite; asp, arsenopyrite.

clusions in which the liquid was trapped as the crystal grew. In general these inclusions are very small, averaging less than 0.001 millimeter in diameter. Those of the second type are generally larger, and the fact that they occur on planes extending across grain boundaries strongly suggests that they were developed subsequent to the crystallization of the occluding quartz, possibly, as suggested by Ferguson [90] for the quartz at Alleghany, by "actual opening of the quartz to allow the introduction of the material—gas or liquid—contained in the bubbles and later healing of the fissures by pressing together of the walls." In a few thin sections of vein quartz lines of vacuoles radiating from a single sulphide grain were observed. These rays passed through two or more adjacent grains without change in direction.

There is a close resemblance between the vacuoles in the quartz of the Grass Valley district and those occurring in the quartz of the Alleghany district described by Ferguson,[91] and the following inferences, which he drew from his studies of the vacuoles at Alleghany, are equally applicable to those from Grass Valley.

> Many quartz crystals show evidence of pulsatory growth; the zones of bubbly and relatively clear quartz indicate changing composition of the solution from which they were derived or changes in the speed of growth of the crystal.
>
> The development of the later vacuoles that occur in rays crossing crystal boundaries probably involved solution along actual fracture planes and partial recementation of the quartz.
>
> The formation of the later series of cavities seems to have been closely associated with the introduction of minerals that replaced the quartz.

One characteristic of the Alleghany quartz [92] that could not be seen with certainty in the Grass Valley sections is the clearing of cloudy quartz by microbrecciation, for in the Grass Valley specimens the variation in cloudiness, due to vacuoles, within a single unbroken crystal appears to be as great as the range in cloudiness between the original crystals and the strain granulation zones. Then too, many of the microbrecciation zones show no change whatever in the distribution density of the vacuoles. This fact is in conformity with my general impression that the mechanical deformation of vein quartz is much greater at Alleghany than at Grass Valley.

Phantom veinlets.—Many thin sections of cloudy vein quartz show minute veinlets of later clear quartz 0.1 to 1.0 millimeter in width. When viewed with plain transmitted light the veinlets contrast strongly with the older, inclusion-filled quartz (pl. 22, *C* and *D*). With polarized light, however, they are not so conspicuous, for the quartz of the veinlets has the same optical orientation as the crystal traversed and extinguished with it. To such veinlets Adams [93] followed Tolman in applying the name "phantom."

Feather quartz.—Several thin sections of quartz from crossing fillings exhibited feather structure (pl. 23, *A*, *B*), made up of nearly parallel prisms having slightly divergent extinction positions. Such quartz appears to be closely related to comb quartz, like it having been deposited in open cavities. Although feather quartz was most commonly observed in crossing fillings, only a small fraction of the total amount of crossing quartz has this structure, and so it cannot be depended upon as a criterion for distinguishing between crossing and vein quartz.

SCHEELITE

Scheelite, calcium tungstate ($CaWO_4$), is a rare mineral in most of the veins of the district. In at least two veins of the Union Hill mine, however, it is an important vein-forming mineral. MacBoyle [94] states: "In the tungsten vein there is a stringer of scheelite from 2 to 7 inches in width associated with quartz, and free gold was found in the scheelite."

The Union Hill mine was flooded during my visits to the district, but I was fortunate in obtaining two polished slabs of vein material containing scheelite which were collected by Frank L. Hess, of the Bureau of Mines, in 1917 and deposited in the National Museum (no. 92403). The large slab is a section of a vein 4 inches wide and is approximately one-half scheelite (pl. 12, *A*). A thin section cut from this specimen (pl. 12, *B*) shows the scheelite to be sheared and cemented by later quartz. Mr. Hess' notes, which he kindly placed at my disposal, state that 8 tons of hand-picked ore averaging 1½ percent WO_3 was taken from the Greek or Tungsten vein during the World War.

In the Empire mine scheelite was observed on the 4,200- and 5,400-foot levels. In a specimen from the 5,400-foot level flesh-colored euhedral scheelite crystals are intergrown with quartz, forming a thin band on both walls. The vein is 3 inches thick, and the center is filled with massive white calcite enclosing a few isolated fragments of quartz and scheelite that appear to have fallen from the hanging wall while filling by calcite was in progress.

These few observations indicate that the deposition of scheelite overlapped the early deposition of quartz, and hence the scheelite belongs to the same age group as does pyrite.

Scheelite also occurs in the Amador mine, adjacent to the Norambagua mine, about 4 miles south of the town of Grass Valley. Fred M. Miller has several specimens of comb quartz enclosing older scheelite from the dump of the Amador.

[90] Ferguson, H. G., and Gannett, R. W., Gold quartz veins of the Allegheny district, California: U. S. Geol. Survey Prof. Paper 172, p. 43, 1932.

[91] Idem, pp. 41-44.

[92] Idem, pp. 42, 44.

[93] Adams, S. F., A microscopic study of vein quartz: Econ. Geology, vol. 15, p. 632, 1920.

[94] MacBoyle, Errol, Mines and mineral resources of Nevada County, p. 255, California State Mining Bureau, 1919.

SERICITE

Sericite ((H,K)$AlSiO_4$) is a common vein mineral and an abundant constituent of the altered wall rocks. In the veins it is usually associated with ankerite, filling cracks and vugs in the vein material. Like ankerite, it replaces vein quartz, and well-developed sericite foils were occasionally observed replacing ankerite (pl. 13, *D*). It is widely distributed in the wall rocks, where it replaces the feldspars and encroaches on the quartz of the granodiorite (pl. 5, *B*, *D*, *E*), diabase, and porphyrite. It is most abundant near the vein fractures, but even the freshest rocks, remote from known veins, have not escaped sericitization in some degree.

The peak of sericitization of the veins occurred during the carbonate substage, after the great bulk of vein quartz had been deposited, and there is no reason for considering the abundant sericite in the wall rock immediately adjoining the veins to be earlier than the quartz.

SILVER MINERALS

The veins of the district contain much less silver than gold. The ratio varies from mine to mine and from year to year, but there is seldom more than one-fourth as much silver recovered as gold. In the 10-year period from 1911 to 1920, the Empire mine produced 0.27 ounce of silver to each ounce of gold.

Some of the galena of the district is silver-bearing, as a few of the specimens examined gave faint growths of silver bichromate crystals when the ammonium bichromate test [95] was made. On most samples the test was negative.

Mr. Nobs kindly furnished a specimen of ore from the Empire 3,000-foot level assaying 35 ounces of silver and 1 ounce of gold to the ton, an exceptional silver and gold ratio for the district. Galena separated out from this specimen, extracted with nitric acid, and treated under the microscope with ammonium bichromate gave a strong growth of silver bichromate crystals. As no other silver minerals were recognized, the silver in this ore appears to be contained in the galena.

Most of the silver, however, is alloyed with the native gold. The analyses of gold specimens given on page 39 show a uniform silver content amounting to 13 percent of the native gold-silver alloy.

Lindgren [96] reported the occurrence of a heavy mass of tetrahedrite containing 1 percent of silver in the Osborne Hill mine, and pyrargyrite, stephanite, and argentite in a specimen from the Allison Ranch mine, now in the National Museum (no. 14967). Though silver-bearing tetrahedrite is abundant in some of the mines of Nevada City, it is rare at Grass Valley.

[95] Short, M. N., Microscopic determination of the ore minerals: U. S. Geol. Survey Bull. 825, pp. 148-150, 1931.

[96] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 119.

SPECULARITE

[See hematite]

SPHALERITE

Sphalerite (ZnS) is an abundant and widely distributed mineral, occurring in all the veins of the district. Although most sphalerite is dark brown, some greenish-yellow to pale yellow specimens were observed on the 8,600-foot level of the North Star mine and in the Golden Center mine. This mineral is usually associated with galena, and both are later than pyrite. Much of the sphalerite contains minute inclusions in the shape of rods and dots, which are believed to be due to "unmixing" or "exsolution." Sphalerite replaces the older pyrite and may replace quartz (pl. 14, *D*).

TELLURIDES

Lindgren [97] tested samples of various mill concentrates for tellurium and usually obtained negative results. The Idaho-Maryland concentrate, however, contained 0.03 percent of that metal. Hessite (Ag_2Te) and altaite (PbTe) have been identified in the Nevada City veins, and M. N. Short,[98] of the Geological Survey, identified altaite in an ore specimen from the 5,000-foot level of the Empire mine.

I am informed that several tellurides have been identified in ores from the Idaho-Maryland mine, but the material has not been accessible to me for study.

WAD

Wad, an impure mixture of manganese oxides, forms thin crusts and stains in the upper levels of most of the mines. Though sufficiently widely distributed to be considered a common mineral, it is nowhere abundant.

PARAGENESIS OF THE VEIN-FORMING MINERALS

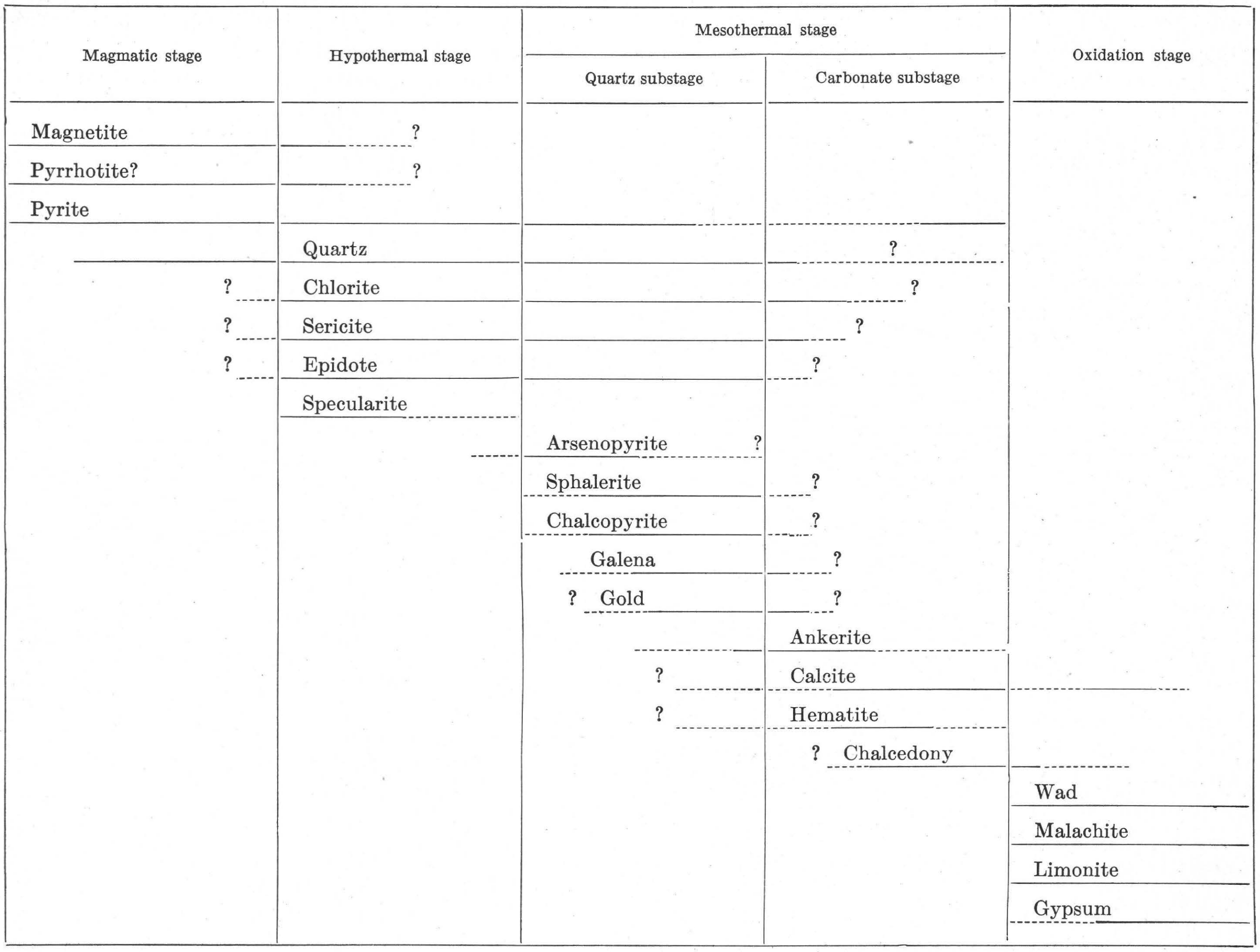
STAGES OF MINERALIZATION

The paragenetic relations of the principal vein-forming minerals are indicated in the following table. The four main stages of mineralization are the magmatic stage; the hypothermal stage; the mesothermal stage, which includes the quartz and carbonate substages; and the oxidation stage.

[97] Idem, p. 117.

[98] Oral communication.

Paragenesis of the vein minerals at Grass Valley, Calif.



MAGMATIC STAGE

A few vein-forming minerals also occur as primary constituents of the igneous rocks of the area. Magnetite is abundant in the serpentines, pyrrhotite and primary pyrite are accessory constituents of diabase and porphyrite, and quartz is an essential constituent of many rocks. To what extent such secondary minerals as chlorite, sericite, and epidote were developed in the wall rocks soon after their consolidation and so are related to magmatic mineralization is uncertain. Their wide and general distribution, remote from vein fractures, lends some weight to the idea that they may have begun to form prior to vein filling. There is, however, no positive evidence on this point.

HYPOTHERMAL STAGE

A high-temperature stage of mineralization is represented by the Crown Point vein and by a single crossing in the Empire mine.

Pyrrhotite is a common mineral in the Crown Point mine dump and in the Crown Point vein, where it is intersected by the 4,200-foot level crosscut at the north end of the Empire mine. There pyrrhotite, magnetite, and pyrite are the principal metallic minerals. Lindgren [99] records a small deposit of magnetite "in the diabase near the granodiorite contact, 4,000 feet east of the Omaha mine, in Diamond Creek."

Blades and rosettes of specularite embedded in a groundmass of chlorite and later carbonates fill a strong crossing fracture exposed on the north drift of the 4,600-foot level of the Empire mine. The crossing also contains a small amount of pyrite.

The pyrrhotite-magnetite-specularite mineral suite presumably represents a higher-temperature and older stage of mineralization than is represented by the gold quartz veins. No evidence of zoning was observed.

Some sericite, epidote, and chlorite may belong to this stage.

MESOTHERMAL STAGE

Lindgren [1] has assigned the gold quartz veins of the district to the mesothermal stage of mineralization. The contrast between the earlier quartz and the later carbonates is so great that it seems advisable to sub-

[99] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 120.

[1] Lindgren, Waldemar, Mineral deposits, 3d ed., p. 621, McGraw-Hill Book Co., 1928.

divide this stage into two substages—an older one in which quartz is the principal gangue mineral and a younger one marked by the deposition of carbonates. A similar subdivision was made by Ferguson and Gannett [2] at Alleghany.

Quartz substage.—Pyrite and arsenopyrite are the earliest vein sulphides. They are generally cracked or broken and are cemented in a matrix of contemporaneous or slightly later quartz. Somewhat later sulphides are sphalerite, chalcopyrite, and galena. The chalcopyrite is present mainly as isolated rods and dots in the sphalerite, and the galena, in polished sections, appears to be slightly later. The gold is associated with galena and appears to be contemporaneous with it. It fills cracks in the broken pyrite crystals or is deposited upon the surface of the crystals. Gold also occurs remote from sulphides, more commonly in sheared zones than in massive quartz. Scheelite and molybdenite were deposited in this substage, but their paragenetic relations with the common sulphides could not be determined. Epidote, sericite, and chlorite were deposited throughout the sequence.

Quartz is the dominant gangue mineral of this substage. It is probably in part earlier than the pyrite and arsenopyrite of the veins, but its deposition continued into the later carbonate substage. Wide veins show successive generations of quartz, suggesting that its deposition came in repeated pulses alternating with movement of the vein walls.

Carbonate substage.—It is impossible to draw a sharp line between the quartz substage and the later carbonate substage. There appears rather to have been a gradual but pulsating depletion of quartz-depositing solutions and a corresponding increase in carbonate solutions. Such a concept is suggested by the alternate rims of carbonate and quartz, as shown in plate 16. Thin sections of euhedral quartz crystals embedded in carbonate show under high magnification a ragged transitional border between the quartz and carbonate, suggesting that quartz deposition gradually gave way to carbonate deposition. This transitional period, however, occupied only a fractional part of the carbonate substage. Ankerite of variable composition filled cracks, fissures, and vugs in the quartz veins, embedding the earlier quartz in a contrasting matrix. Generally later than ankerite, which is the principal vein carbonate, clear calcite in smaller amounts filled the remaining interstices and was deposited in fractures opened late in the substage. In a few places the calcite contains inclusions of an earthy hematite. With this calcite came a final generation of quartz that is free from the inclusions and vacuoles marking the earlier quartz. This clear quartz fills the latest fractures, forming the "phantom veinlets" described on page 43.

Chalcedony and, more rarely, opal mark the final stages of siliceous deposition. Neither mineral is abundant, but small amounts of chalcedony were observed in most of the veins of the district.

Postcarbonate chlorite (pl. 13, *B*) was observed in a few specimens, and sericite replacing vein carbonates (pl. 13, *D*) is not uncommon.

OXIDATION STAGE

Few supergene minerals occur in the quartz veins of the district. Thin crusts of wad are found in the upper levels of many of the mines, and stains of copper carbonates appear here and there on the vein walls. Much limonite is being deposited today in the upper and abandoned mine workings, forming fragile stalactites and stalagmites and covering the drift floor with a brown crust. Fishtail crystals of gypsum a few millimeters in length are to be seen in the walls of old workings, and on the 1,500-foot level of the North Star mine a section of the drift floor was covered to a depth of several inches by a white soupy mixture of gypsum crystals and water.

The principal supergene mineral, limonite, is the oxidation product of pyrite contained in the diabase wall rocks of the upper levels. Gypsum is being formed by the action of sulphuric acid, liberated in this oxidation process, upon carbonates in the wall rock.

ORE SHOOTS

GENERAL FEATURES

An ore shoot is the part of a vein that contains metals of sufficient value to be mined with profit. As its limits are determined by assay walls whose location is dependent upon mining costs and the selling price of gold, an ore shoot is, in a strictly geologic sense, an artificial unit whose size and shape may vary with changing mining economics. To a large extent, however, the localization of gold is controlled by such structural features as crossings, splits, and abrupt changes in dip and strike of the vein.

That gold was deposited only in those channels to which gold-bearing solutions had access is axiomatic. Many factors, however, entered into the localization of these channels. We know that quartz deposition was an intermittent process, many times interrupted by movements of the vein walls, and that the period of gold deposition was much shorter than that of quartz. Thus, in a strong and persistent quartz vein gold may be confined to the single vein segment or to the single quartz strand that was open when the gold-bearing solutions were in circulation.

[2] Ferguson, H. G., and Gannett, R. W., Gold quartz veins of the Alleghany district, California: U. S. Geol. Survey Prof. Paper 172, p. 39, 1932.

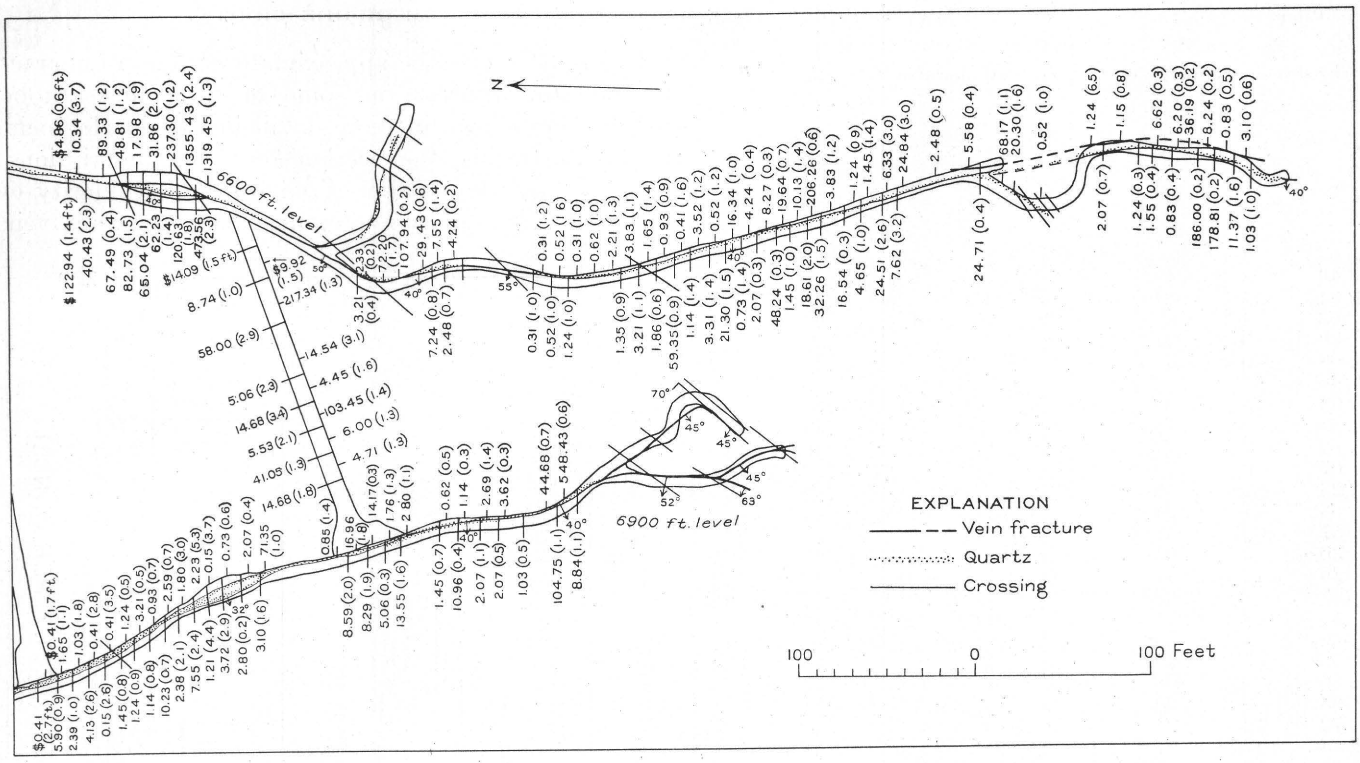


FIGURE 30.—Distribution of gold in the south end of the No. 2 vein, 6,600- and 6,900-foot levels, North Star mine. The first figure is the assay value in dollars per ton (gold at $20.67 an ounce) and the second figure is the thickness in feet of the vein sampled.

In many places where gold ore shoots either end against crossings, are localized at vein intersections, or are dissipated by numerous vein splits, the structural control of the ore shoots is evident; in many other places, however, structural control is not so evident, and we are forced to seek an explanation in the assumption that later movements have masked the original structures or that gouge or breccia has dammed the barren vein segments, effectively excluded the gold-depositing solutions, or, more vaguely, that the little-known optimum of chemical and physical conditions for gold deposition did not prevail.

DISTRIBUTION OF GOLD

The distribution of gold in the ore shoots is subject to extremely erratic variations along both strike and dip. Commonly samples showing assay values of several hundred dollars a ton adjoin others yielding values of only a few cents. Ore is determined not only by assay value but also by the width of the vein. Thus the cost of mining a 2-inch vein carrying $40 a ton would be greater than the value of the gold recovered, while a 5-foot vein assaying $10 a ton could be mined with profit. It is customary to include both vein width and gold content on the assay sample maps. Such a map, which may be considered characteristic of the veins of the district, is shown in figure 30. In figures 31 and 32 assay values and vein width are shown graphically, and the accompanying table gives the gold content and the width of the sampled section for some of the veins of the North Star mine.

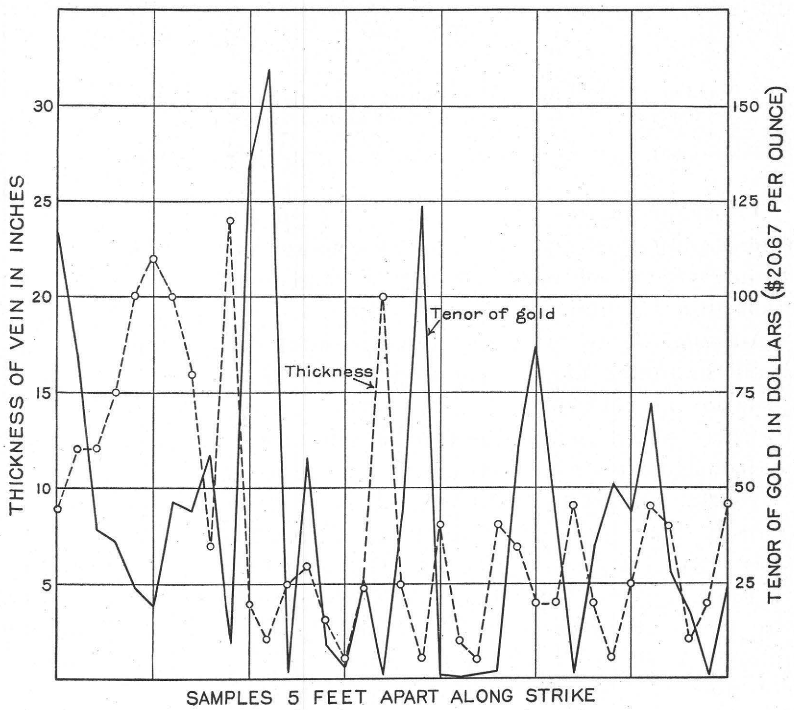


FIGURE 31.—Thickness and assay value of a part of the Phoenix vein on the 200-foot level north of the shaft.

Variations in gold content and thickness along the strike of several veins in the North Star mine

[Gold content in ounces to the ton, and vein thickness in inches. Samples were taken 5 feet apart]

1		2		3		4	
Gold	Thickness	Gold	Thickness	Gold	Thickness	Gold	Thickness
0. 62	14	0. 06	3	0. 01	30	0. 03	3
1. 40	12	. 16	4	. 16	31	. 04	6
1. 31	14	. 21	5	. 03	3	2. 01	8
. 63	14	. 01	11	. 19	14	. 83	8
. 86	9	. 16	7	1. 95	4	. 44	18
. 08	20	. 70	32	. 04	8	. 25	13
1. 40	7	. 23	12	. 14	6	. 06	3
. 03	8	. 38	14	. 26	5	. 04	10
. 24	8	. 18	16	. 03	17	. 06	14
. 62	12	. 71	18	. 02	18	. 08	16
. 07	10	. 20	23	. 04	16	. 48	12
. 23	4	2. 10	7	. 02	14	. 18	16
1. 03	4	. 24	8	. 24	10	. 43	12
1. 07	5	. 51	16	. 14	8	. 30	18
. 30	3	. 04	20	. 09	4	2. 64	20
. 36	12	1. 44	15	. 01	10	7. 81	24
. 03	4	2. 98	13	1. 95	10	6. 57	12
. 58	8	. 11	14	. 09	8	. 62	16
. 20	8	. 30	16	. 14	6	. 61	12
. 02	2	. 48	36	. 27	5	8. 98	24
. 36	3	. 08	36	. 01	6	. 02	16
. 03	2	. 20	29	. 24	11	1. 32	14
. 72	2	. 04	32	3. 50	4	1. 73	16
2. 48	2	. 14	14	. 01	3	. 10	26
. 37	5	. 10	16	. 23	10	. 05	16
. 97	2	. 11	27	. 02	7	. 03	26
. 08	6	. 61	12	. 84	4	. 06	30
. 22	5	. 14	30	. 11	4	. 04	36
. 56	8	. 01	6	. 13	3	. 02	40
. 10	30	. 03	5	. 01	4	. 10	10
. 38	6	. 03	22	. 28	3	. 13	8
. 32	4	. 04	22	------	------	. 50	26
. 03	2	. 05	11	------	------	. 69	20
. 02	6	. 05	6	------	------	. 02	8
. 01	6	. 04	10	------	------	. 18	6
. 02	2	. 06	3	------	------	. 04	14
------	------	. 05	8	------	------	. 22	12
------	------	------	------	------	------	. 03	36

1. No. 3 vein, 8,600-foot level, between stations 5301 and 5196.
2. No. 2 vein, 7,500-foot level, between stations 5194 and 5226.
3. X vein, 7,500-foot level, between stations 4701 and 4738.
4. No. 3 vein, 9,000-foot level, between stations 5253 and 5229.

A broader picture of the distribution of gold in the veins is obtained by averaging the assays of samples from each car of ore mined in a single stope area. Such an assay map is shown in figure 33.

Although more or less systematic sampling is done in all the mines, most of the underground foremen can estimate the gold content of the veins with remarkable accuracy, and much of the routine mine assaying is in confirmation of their estimates.

Quartz containing visible gold is irregularly and sparsely distributed throughout the veins. During the early years of the district, in the early fifties, such "high-grade" or "specimen" ore was the principal lure to quartz mining, and some of the early mines, notably the Gold Hill and Allison Ranch, contained rich pockets. Today ore showing visible gold is occasionally found in all the mines.

FORM OF ORE SHOOTS

Figure 34 shows the approximate outlines of characteristic stoped areas on some of the veins. Stope outlines are shown in more detail in the development maps illustrating the section on mine descriptions. All the stopes are characterized by the irregularity of their outlines and by numerous pillars of barren vein

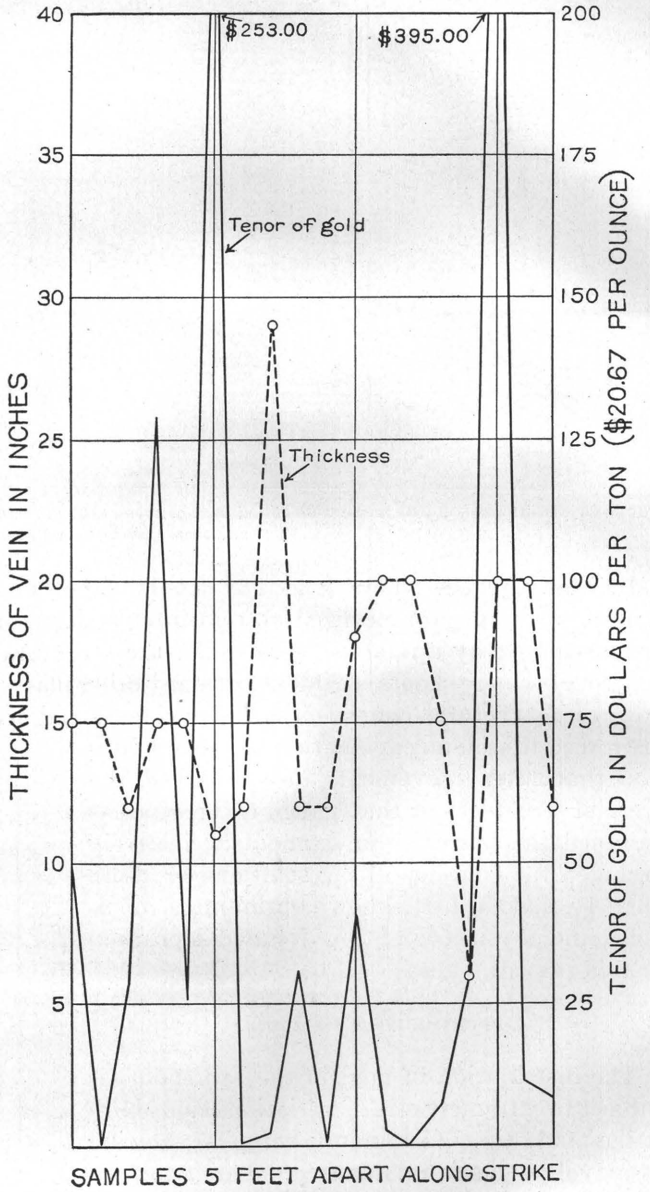


FIGURE 32.—Thickness and assay value of a part of the 500-foot level of the Church Hill vein, Golden Center mine.

material. Many ore shoots are elongate bodies whose long axis makes an angle with the dip of the vein.

The relation of the pitch of the ore shoot to the dip of the vein was formulated by Lindgren[3] in the following "law": "The shoot will, as a rule, pitch to the left of an observer standing on the apex of the vein and looking

[3] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 160.

down in the direction of the dip." This relation is conspicuous where the ore shoots are elongate, as in the North Star, A, and Dromedary veins, but where the ore shoots do not show definite elongation, as in parts of the Empire mine, the "law" is of little value as a guide to exploration.

In the granodiorite area crossings that strike northeast exercised a strong structural control upon the opening and closing of vein fractures during mineralization, and they commonly form the lateral boundaries of ore shoots. In the granodiorite area most of the productive veins, whose ore shoots have been delineated by mining, strike north and dip either east or west or strike northwest and dip northeast. The reason for the "left pitch" of ore shoots appears to lie in the fact that the intersections of the northeastward-striking crossings with all these veins pitch to the left, and the structural control which the intersections exercised upon vein filling is reflected in the shape of the ore shoots.

Within the serpentine area of incompetent rocks the crossings exercised less control during mineralization than they did in the granodiorite area, and the left pitch of the famous Eureka-Idaho ore shoot (fig. 64) is due to some other and less obvious cause.

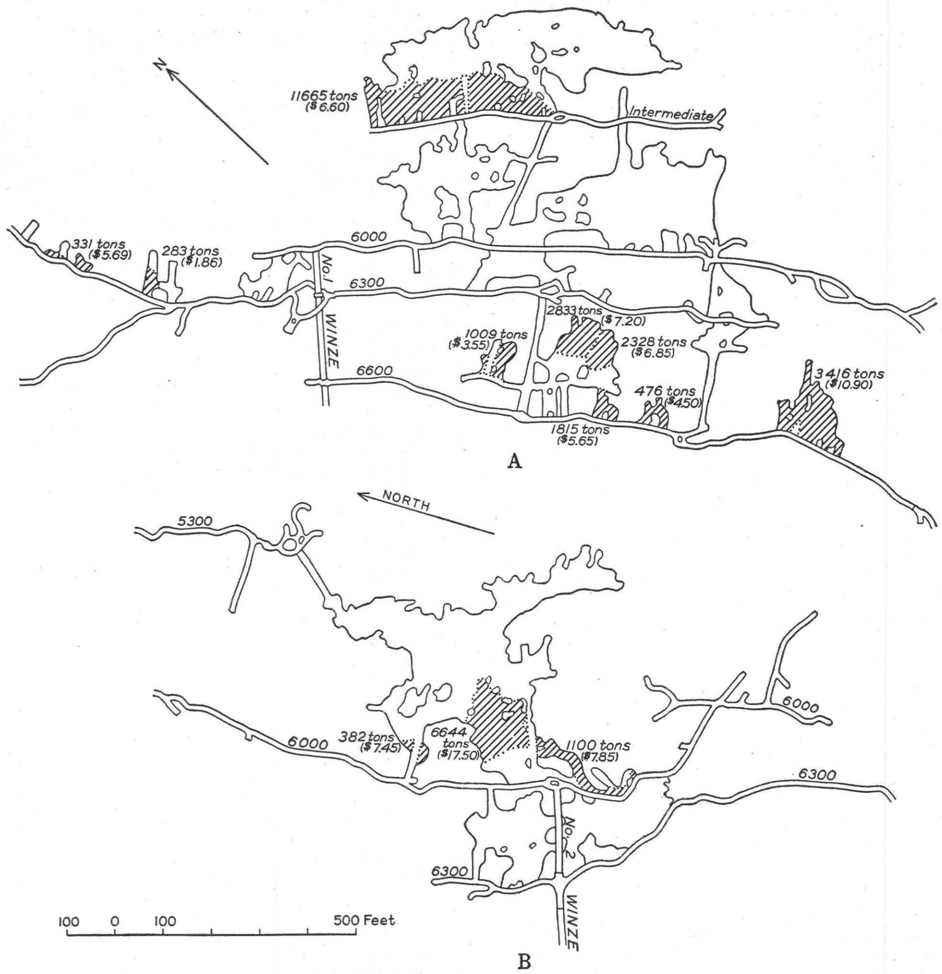


FIGURE 33.—Distribution of gold, as determined by car samples, in some stopes in the North Star mine. Stope areas that were sampled are shaded. A, X vein, 6,000- to 6,600-foot levels. B, No. 2 vein, 5,300- to 6,300-foot levels. These stopes were mined in 1924–25.

Ore shoots vary greatly in size. The Eureka-Idaho shoot was over 5,000 feet in length and extended from a short distance below the surface to a depth of 2,000 feet. Ore shoots in the Empire and North Star mines attain a pitch length of 2,000 feet. Others are much smaller, as is shown in the development maps of the various mines.

Ore shoots are independent of the chemical character of the country rock, for in the serpentine area serpentine, diabase, and amphibolite schist form walls, while in the granodiorite area shoots pass from diabase to granodiorite without change. The physical character of the wall rock is important only insofar as it controls fracturing and so affords channels for mineralization.

PERSISTENCE IN DEPTH

The North Star mine has attained a vertical depth of 3,700 feet and the Empire mine of 3,600 feet below their shaft collars. Although some ore shoots have been bottomed, deeper ones have been discovered, and although some veins have been lost, others have been found. In that vertical range of more than 4,000 feet, for the mines as a whole, neither the strength and character of the vein fractures nor the character of mineralization has changed.

Coarse free gold was found in stopes below the 8,600-foot level of the No. 3 vein of the North Star mine, and recently a new ore shoot was discovered on the south end of that level.

While differing in many details, the gold-quartz veins of the Grass Valley and Nevada City districts are of the same general type as those of the Mother Lode and the Alleghany district and must have been formed under similar conditions of pressure and temperature in approximately the same depth zone. Veins have been followed by mining operations to a vertical depth of 5,700 feet on the Mother Lode and 2,000 feet at Alleghany. As erosion above the present land surface has removed the upper parts of the veins, and as they have nowhere been bottomed in mining operations, there is exposed a vertical segment some 5,000 feet in depth through which gold-quartz veins persist.

The original upward extension of the known gold-quartz zone involves estimates of the amount of rock eroded since the veins were formed. From several independent lines of evidence Ferguson[4] has estimated that erosion has removed at least 10,000 feet of rocks above the present surface at Alleghany since the veins were formed. Grass Valley is somewhat lower down on the western slope of the Sierra Nevada, but his estimate for Alleghany gives some measure of the order of thickness of the rocks eroded from the Grass Valley district and an approximate upper limit of the gold-quartz veins.

As the veins at Grass Valley have been followed to a vertical depth of 4,000 feet without recognizable change in either the character of the vein fractures or the type of mineralization, there is no reason for believing that the lower limit of gold deposition has been approached. It appears more likely that such economic factors as mining and development costs rather than the bottoming of the gold veins will determine the depth of mining in this district.

PROBABILITY OF NEW DISCOVERIES

Among the apocryphal legends of the district is this statement, attributed to Mr. George Starr: "Successful mining in Grass Valley is accomplished only by doing too * * * much development work." In the North Star mine the A, Y, and X veins (pl. 26) were found while mining in the North Star vein, and a prospect drift on a barren seam led from the X to the No. 2 vein. The X vein was first developed from the Pennsylvania vein, and the Garage and Church Hill veins of the Golden Center mine were found by crosscutting from the Dromedary vein. Within the last few years the Newmont vein has been developed in the Empire mine. Many more examples might be cited in which exploratory crosscuts led to new veins, and drifts on barren seams led to new ore shoots.

At Grass Valley, as in many other gold camps where the veins are relatively narrow and the ore is irregularly distributed, the blocked-out ore reserves are seldom large, and mining treads closely on the heels of discovery. As continued successful mining is largely dependent upon a vigorously executed development program, a considerable item in the mining budget must be set aside for exploratory crosscuts, drifts through barren ground, and diamond drilling in the vein walls.

It is generally admitted that chance plays an important part in all mining discoveries. In the Grass Valley district many long crosscuts have been driven without reward, and large sums have been spent in drifting on barren fissures that did not lead to new ore. Some insurance against excessive unsuccessful development

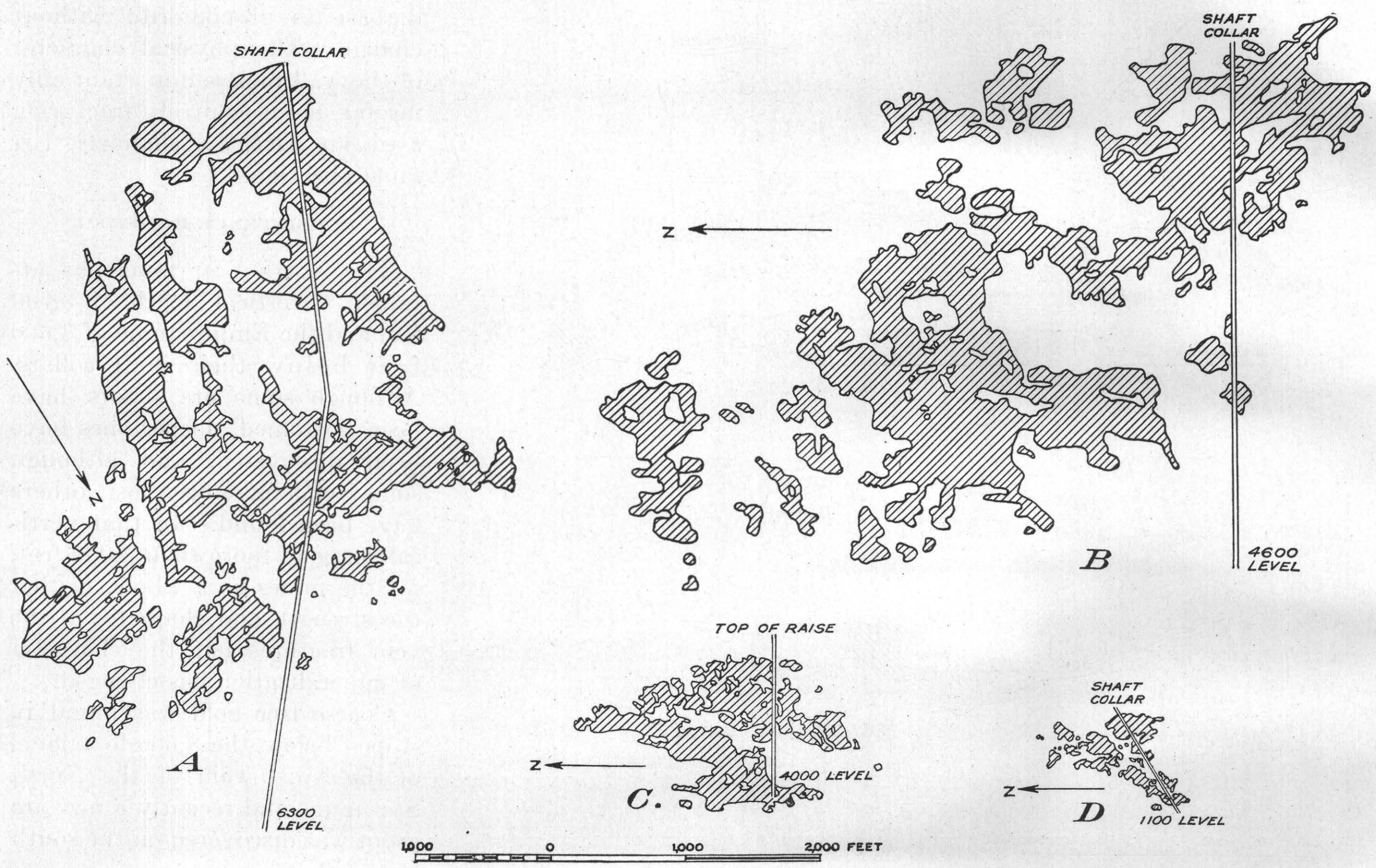


FIGURE 34.—Form of ore shoots, *A*, North Star vein, North Star mine; *B*, Empire and Rich Hill veins, Empire mine; *C*, A vein, North Star mine; *D*, Dromedary vein, Golden Center mine.

[4] Ferguson, H. G., and Gannett, R. W., op. cit. (Prof. Paper 172), pp. 61–70.

work is afforded by spreading the exploration over different parts of the underground workings, and the larger mines always have several development drifts and crosscuts being driven simultaneously.

In the Empire and North Star mines one discovery has led to another over a period of 80 years. Both mines have experienced lean years that threatened their lives, but new discoveries, financed by profits of prosperous years, have revived them. Other mines have been unable to survive the depletion of known ore, for lack of capital reserves to finance extended development work.

Although the total length of underground workings is measured in hundreds of miles, the district is by no means thoroughly explored. The chance for new discovery is greatest in the larger mines, because of the relatively greater volume of rock to which their workings give access and because they have the working capital to explore it. Because of the ease with which ore shoots can be missed, as in the Idaho-Maryland mine, there is some reason to suppose the existence of ore in many veins in the district that are not now being worked. The cost of discovery, however, may be so high as far to exceed its value. There chance will play an important part.

The concept of fortuitous discovery in its simplest form, as applied to the district, is illustrated in figure 35.

HYDROTHERMAL ALTERATION OF THE WALL ROCKS

GENERAL FEATURES

There is little to be said in elaboration of Lindgren's excellent discussion[5] of the chemical alteration of the wall rocks. As he pointed out,[6] hydrothermal solutions introduced three principal classes of minerals into the rocks—carbonates, sericite, and sulphides. In addition, lesser amounts of chlorite and epidote were formed. Quartz rarely replaces the wall rocks, although it commonly fills small fractures adjacent to veins, in many places of such great complexity as to suggest large-scale replacement when viewed in place or in hand specimens. Under the microscope, however, the quartz of the veinlets is in sharp contact with the carbonatized and sericitized country rock, and evidence of encroachment upon the rock minerals is wanting.

The most certain criterion for the recognition of the degree of alteration of a given rock is the amount of carbonates it contains. In thin section ankerite and calcite are readily recognized, and the amount of CO_2 reported in an analysis is an index to the amount of carbonate present. Carbonates replace feldspars, augite, hornblende, and less commonly quartz. A few euhedral calcite rhombs were observed in thin sections of altered rocks, but more commonly the carbonates preserve in some measure the original texture of the rock.

Sericite, like the carbonates, is widely developed in the rocks of the district. It appears first in the feldspars, then in the augite and hornblende, and finally replaces quartz. Plate 5, *E*, shows altered granodiorite in which sericite is encroaching on quartz, the only remaining original rock mineral. In many places along the veins of the district included fragments of granodiorite and diabase have been completely replaced by sericite. Such fragments are light gray, unctuous, and soft. Even where completely surrounded by quartz they preserve the angular shape of the original rock fragments. Sericite seldom preserves the texture of the original rock. Individual foils are euhedral against all replaced rock minerals. In serpentine areas the chromium mica mariposite has a habit similar to sericite.

Pyrite and to a lesser extent arsenopyrite form small euhedral crystals in the wall rocks, replacing any of the original rock minerals. In the North Star mine

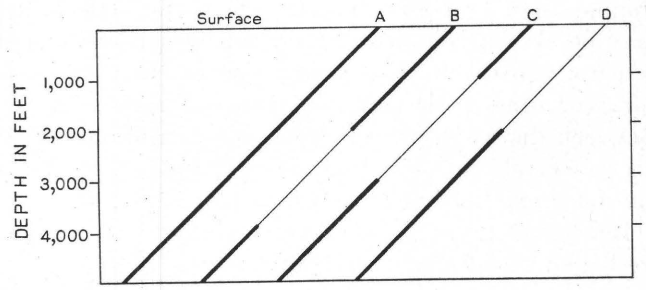


FIGURE 35.—Diagram illustrating the fortuitous discovery of ore shoots. In the hypothetical veins A, B, C, and D ore shoots are shown by heavy lines. As A, B, and C have gold in the outcrops, shafts would be sunk on those veins, while D, which is barren in the outcrop, would be explored, at best, for a few hundred feet. Sinking on veins B and C would likely be stopped before the deeper shoots were found. Thus mining would be limited to vein A and the upper shoots on veins B and C. The deeper shoots on veins B, C, and D, unless found by crosscutting from vein A, would in all probability remain undiscovered.

pyrite appears to be more common in the diabase than in the granodiorite, although pyrite is locally abundant in granodiorite. Pyrite is more closely restricted to the immediate walls of veins and crossings than either sericite or carbonates. It appears to be most conspicuously developed along a few crossing fractures in diabase, where it forms a band several feet in width in which at least half of the original rock is replaced.

Chlorite is a widespread hydrothermal mineral, but it is largely confined to the pyroxene and amphiboles of the wall rock. Commonly it replaces uralitic hornblende, as shown in plate 5, *F*. A more unusual occurrence, where it forms wormlike replacements in quartz and calcite, is shown in plate 13, *B*. Epidote stains border many crossings, and idioblastic epidote crystals replace dike rocks.

The failure of silica to replace the wall rock was clearly stated by Lindgren,[7] who says:

> Replacement by silica is not among the processes here recognized. It should be borne in mind that a rock shattered and filled with quartz seams is not an evidence of metasomatic replacement by quartz, nor is such a rock a quartz vein in process of formation. In a mineral water containing carbon dioxide, sulphureted hydrogen, carbonates, and silica, the former three

[5] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), pp. 145–157.

[6] Idem, pp. 146–147.

[7] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 147.

compounds will vigorously attack, by chemical processes, the minerals of any ordinary rock and form new compounds, while the silica is inert and plays a passive role.

The chemical changes in the wall rocks accomplished by the hydrothermal solutions which traversed them are the introduction of carbon dioxide, potassium, and sulphur and the loss of silica and sodium.

ALTERATION OF GRANODIORITE

All the granodiorite of the area is hydrothermally altered to a greater or lesser degree. Specimens that appear perfectly fresh upon microscopic examination in thin section, show secondary carbonates and sericite developed at the expense of the feldspars, and chlorite replacing the hornblende. In the freshest specimens these alteration products form perhaps 5 percent by volume of the rock. At the opposite extreme are fragments of granodiorite included in the veins which may be almost completely replaced by carbonates and sericite, a little much-corroded quartz being the only survivor among the original essential rock minerals. Between these extremes are rocks showing intermediate degrees of alteration. Photomicrographs of fresh and altered granodiorite are shown in plate 5, *C*, *D*.

Lindgren[8] gives the following analyses of a fairly fresh and an altered granodiorite:

Analyses of granodiorite

	1	2
SiO_2	63. 85	58. 43
Al_2O_3	15. 84	17. 40
Fe_2O_3	1. 91	. 77
FeO	2. 75	[1] 2. 19
MgO	2. 07	1. 50
CaO	4. 76	5. 25
Na_2O	3. 29	1. 76
K_2O	3. 08	4. 03
H_2O-	. 28	. 30
H_2O+	1. 65	2. 61
TiO_2	. 58	------
CO_2	------	4. 04
P_2O_5	. 13	. 13
MnO	. 07	None
BaO	. 06	None
SrO	Trace	------
Li_2O	Trace	------
FeS_2	. 04	1. 59
	100. 36	100. 00

[1] Unsatisfactory on account of FeS_2.

1. Fresh rock from Kate Hayes Hill. W. F. Hillebrand, analyst.
2. Altered rock from Empire mine. George Steiger, analyst.

The rocks are probably not strictly comparable, as the higher Al_2O_3 content of the altered rock suggests that it is more dioritic than the fresh rock. Nevertheless there is a marked decrease of SiO_2 and Na_2O due to solution of the feldspars, and increase of K_2O due to introduced sericite, of CO_2 due to introduced ankerite, and of FeS_2 as pyrite. Neither rock appears in thin section to be notably porous. The gains and losses of each chemical constituent are shown graphically in figure 37.

[8] Idem, pp. 42, 149.

From a microscopic examination of thin sections of granodiorite in various stages of alteration the following general sequence of preferential replacement was established:

1. Sericite and carbonates replace feldspars.
   Chlorite replaces hornblende.
   Pyrite replaces all minerals present.
2. Sericite replaces carbonates and chlorite.
3. Sericite replaces quartz.

Well-formed pyrite crystals have grown against all minerals, and sericite against all except pyrite. Foils of sericite in ankerite are shown in plate 13, *D*.

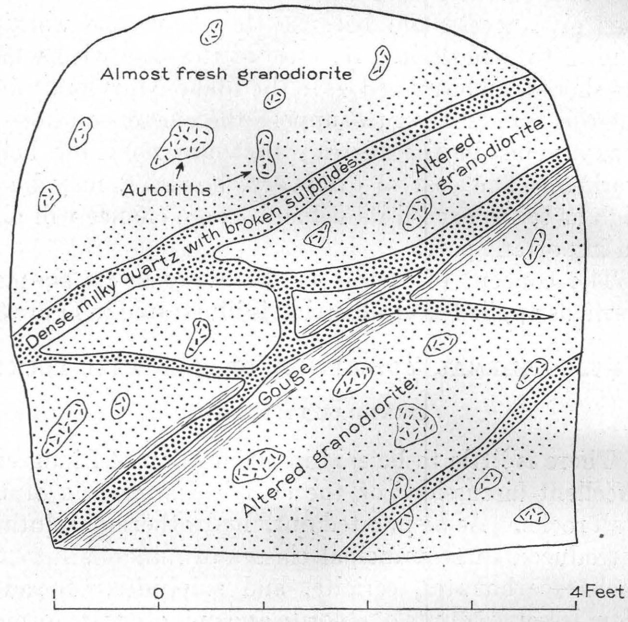


FIGURE 36.—Sketch of drift face on 9,000-foot level of No. 3 vein, North Star mine, showing zone of carbonate alteration (shaded) in the granodiorite along the vein.

Samples of granodiorite were collected along several crosscuts at varying distances from the vein in order to study the change in degree of alteration as the vein was approached. Alteration is most intense immediately adjacent to the veins and, in general, decreases away from them, but it was found that the degree of alteration expressed either in a chemical analysis or in a mineralogical description was not a reliable measure of the distance from the vein, for although alteration proceeds principally along vein fractures, it is not confined to them but follows crossings, minor fractures, sheeting, and joints throughout the granodiorite. In some places fairly fresh granodiorite is found within a few feet of major veins, and in other places highly altered granodiorite borders minor fractures remote from known veins.

Figure 36 is a sketch of a drift face on a narrow vein where the granodiorite, within a few inches of one of the quartz segments, is almost fresh.

ALTERATION OF DIABASE AND PORPHYRITE

The greenstones show a wide variation in the degree of alteration. The freshest-appearing diabases have feldspars somewhat clouded by sericite, and carbonates and shreds of chlorite invade the hornblende. From these slightly altered rocks there is a continuous series showing increased alteration ending in rocks composed mainly of sericite and ankerite. The highly altered rocks are confined to the immediate walls of the principal vein and crossing fractures or to fragments included in the veins. Chlorite is developed early in the alteration process and is commonly later replaced by sericite. Some of the porphyrites that contain phenocrysts of both augite (or hornblende) and plagioclase show both chloritic and sericitic replacement. Plate 4, *D*, shows a quartz porphyrite dike rock in which an augite phenocryst has been partly replaced by chlorite and a plagioclase phenocryst has been completely replaced by sericite and ankerite.

Commonly diabase and porphyrite bordering the veins have been converted into a dark-gray carbonaceous rock that effervesces freely with hydrochloric acid. In thin section such rocks retain some suggestion of the original texture, but the primary minerals have been completely replaced by sericite, ankerite, calcite, and chlorite.

The following analysis of an altered uralite diabase from the North Star mine is taken from Lindgren's report:[9]

Analysis of altered uralite diabase

[W. F. Hillebrand, analyst]

SiO_2	45.74	H_2O+	1.07
Al_2O_3	5.29	TiO_2	.36
Fe_2O_3	.13	CO_2	18.91
FeO	2.06	MnO	.26
MgO (approximate)	.94	BaO	Trace
CaO	23.85	Li_2O	Trace
Na_2O	.11	FeS_2	.49
K_2O	1.29		
H_2O	.22		100.79

On the assumption that sericite has the formula $K_2O.2H_2O.3Al_2O_3.6SiO_2$, the approximate mineral composition may be computed in round numbers from the analysis as follows:

Plagioclase	3.5
Quartz	40.0
Ankerite	7.0
Calcite	37.0
Sericite	12.0
Pyrite	.5
	100.0

Such a calculated mineral composition should be regarded only as approximate, for both the ankerite and sericite molecules are variable and some uralite and chlorite is present.

Highly epidotized diabase and porphyrite were observed bordering several crossings. In thin section the epidote is seen to be idioblastic against all the original rock minerals. Epidotization is generally confined more closely to the immediate walls of fractures than are the more widespread sericite, carbonate, and chlorite alteration products.

ALTERATION OF SERPENTINE

Serpentine is readily susceptible to hydrothermal alteration. Even the freshest specimens, collected from the dump of the New Eureka mine in the northern part of the town of Grass Valley, contain microscopic granular aggregates of carbonates and shreds of sericite.

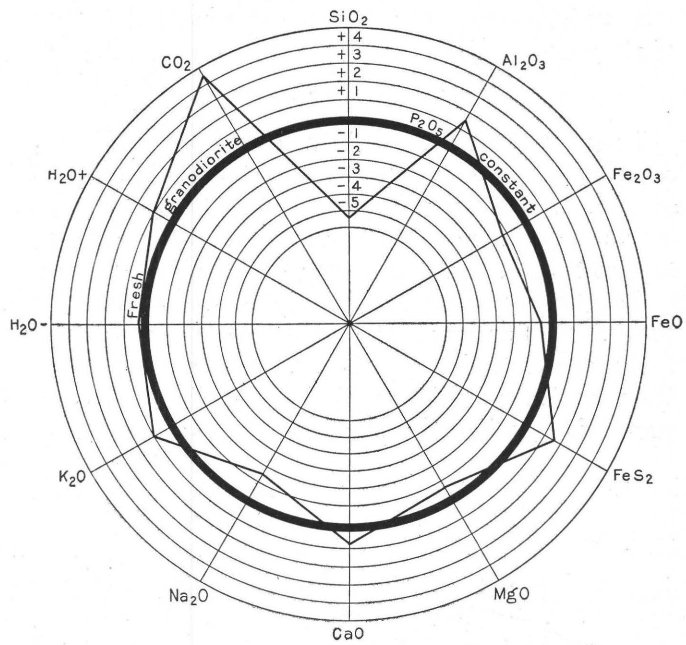


FIGURE 37.—Diagram illustrating gains and losses of each chemical constituent in terms of percentage of mass of the fresh granodiorite. Radial distances between circles represent 1 percent. Gains are outside and losses are inside the heavy circle representing fresh granodiorite. Areas have no significance. The specimens analyzed both contained 0.13 percent of P_2O_5.

More highly altered serpentine loses its luster, and shear faces are covered with a coating of chalky magnesite. The alteration end point is reached when all the serpentine has been corroded to a dull whitish mixture of magnesite, ankerite, chlorite, and sericite. Such highly altered serpentine is cut by the north crosscut on the 4,200-foot level of the Empire mine and is of common occurrence in the district.

Mariposite, a green chromium-bearing mica related to sericite, is abundant in highly altered serpentine and occurs in quartz veins having serpentine walls.

Lindgren[10] gives the accompanying analysis of altered serpentine included in a quartz vein on the sixteenth level of the Idaho-Maryland mine. In describing the analyzed specimen he says:[11]

It is greenish gray and distinctly schistose; remaining films and streaks of greenish serpentine or chlorite appear in a predominant gray, finely granular mass. Under the microscope

[9] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 149.

[10] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 149.

[11] Idem, pp. 153–154.

the principal constituent seems to be magnesite in large grains; there is a little chromite and many veinlets of quartz.

Analysis of altered serpentine

[W. F. Hillebrand, analyst]

SiO_2	36.19	CO_2	21.82
Al_2O_3	4.93	P_2O_5	.05
Fe_2O_3	.21	NiO	.10
FeO	5.36	MnO	.12
MgO	22.94	BaO	Trace
CaO	4.60	SrO	Trace
Na_2O	.16	Li_2O_3	Trace
K_2O	.06	FeS_2	.22
H_2O-	.18		
H_2O+	2.87		99.97
TiO_2	.16		

The high content of CO_2 indicates the extreme degree of alteration of the rock.

ORIGIN OF THE DEPOSITS

The preceding portion of this report has been mainly descriptive. The principal characteristics of the rock formations, fracture systems, vein materials, and wall-rock alteration have been set forth. From this body of fact must come a large part of the evidence upon which any explanation of the origin of the deposits is based. But, as much of that evidence is fragmentary and incomplete, it must be supplemented by evidence from other geologically similar districts and interpreted in the light of our broader geologic concepts. Thus, genetic hypotheses, in a large measure, are a synthesis of knowledge and belief, and it is imperative that they be so regarded.

With the shortcomings of the synthetic approach well in mind, the problems presented by the origin of the fracture systems, the method of quartz deposition, and the source of the vein materials are next examined.

ORIGIN OF THE FRACTURE SYSTEMS

EVIDENCE FOR STRUCTURAL SEQUENCE

Certain features of the distribution of dikes, crossings, and veins that give some clue to the origin of the fracture systems may be briefly summarized.

Numerous dikes cut the granodiorite and extend into the adjoining rock. Mineralogically they fall into two groups—the aplites, which have a fairly uniform composition, and the basic dikes, which have a wide range in composition. The dikes of both groups have sharp and regular walls that show no evidence of assimilation of the wall rock, and some of the aplites show definitely chilled borders. Most of the dikes, like the crossings, strike northeast.

The principal outcropping veins are shown in figure 11. Howe [12] called attention to the preponderance of veins that strike north, parallel to the long axis and

[12] Howe, Ernest, Gold ores of Grass Valley, Calif.: Econ. Geology, vol. 19, p. 603, 1924.

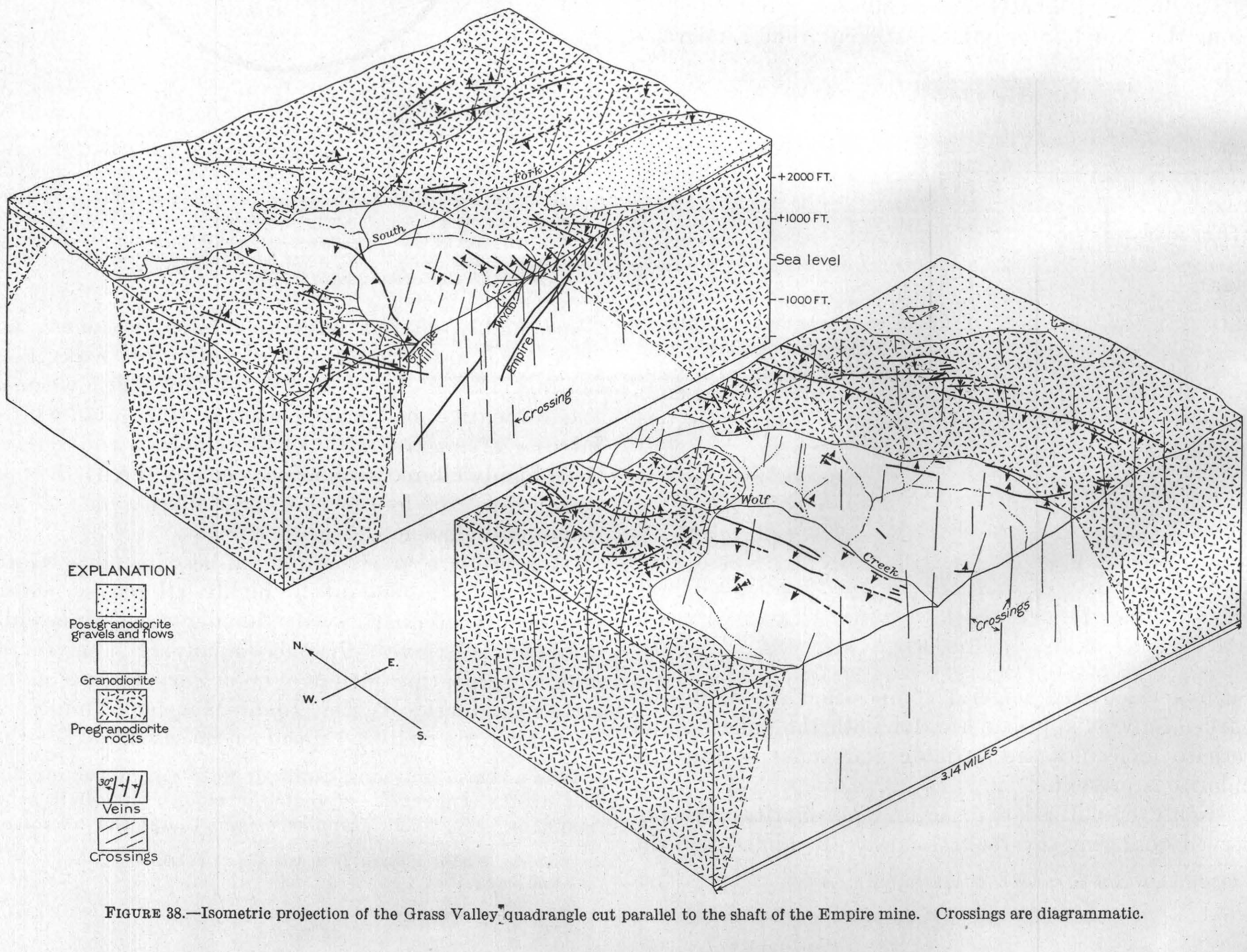


FIGURE 38.—Isometric projection of the Grass Valley quadrangle cut parallel to the shaft of the Empire mine. Crossings are diagrammatic.

walls of the intrusive stock. The W. Y. O. D.-Pennsylvania group of veins strike across the local contact, but, as shown in figure 38, the contact interesected is that of a roof pendant of the older rocks, and these veins, too, may be considered parallel to the main contact. This relation also holds true for most of the veins of easterly strike, notably those in the North Star and New York Hill groups, which also strike parallel to the granodiorite contact at the horizon at which they enter the intrusive.

The principal true exceptions to this parallelism are the Idaho-Maryland and Brunswick group of veins, which are remote from the known granodiorite contact, and the Wisconsin and Omaha group of veins, which cross the intrusive contact at a high angle. Mining development, however, has shown that although the Omaha veins cross the contact, they cannot be traced far into the surrounding rock. Similarly, the veins of the northward-striking Empire system within the granodiorite do not extend beyond the north end of the intrusive, but near the contact they are dissipated in a network of small veins with random strikes.

As pointed out by Lindgren,[13] "each direction of strike has its two directions of symmetrically opposite dip, which are referred to as conjugated systems." Thus, in a pair of veins paralleling some part of the contact between granodiorite and host rock, one vein dips into the intrusive and the other dips into the host rock. In this connection it may be noted that the veins dipping into the intrusive are generally the more persistent.

The vein fractures are not simple breaks but rather are fracture zones of variable width and degree of shattering, within which the veins as defined by the quartz filling are confined. Secondary walls diverge from both the hanging and foot walls of the main vein at low angles. In many places a marked increase in the number of diverging secondary walls furnishes a clue for picking up a parallel quartz vein within the principal outer walls of the same vein zone.

It was possible to determine the displacement on the veins in only a few places where the offset of dikes could be measured. In each place the displacement was in the direction of a reverse fault. The maximum measured movement was about 20 feet. In many places brecciation of the vein filling and gouge seams in the quartz are indications of postmineral deformation.

As shown in the diagrams of strike frequency (fig. 21), all the crossings strike northeast, approximately transverse to the long axis of the intrusion.

The most reliable criteria for determining the relative ages of the dikes, crossings, and vein fractures are afforded by the character of their intersections where crosscutting relations with or without offsetting can be observed. Although crosscutting relations are not as abundant as might be desired, several definite underground exposures have been found, as shown in figures 39–42.

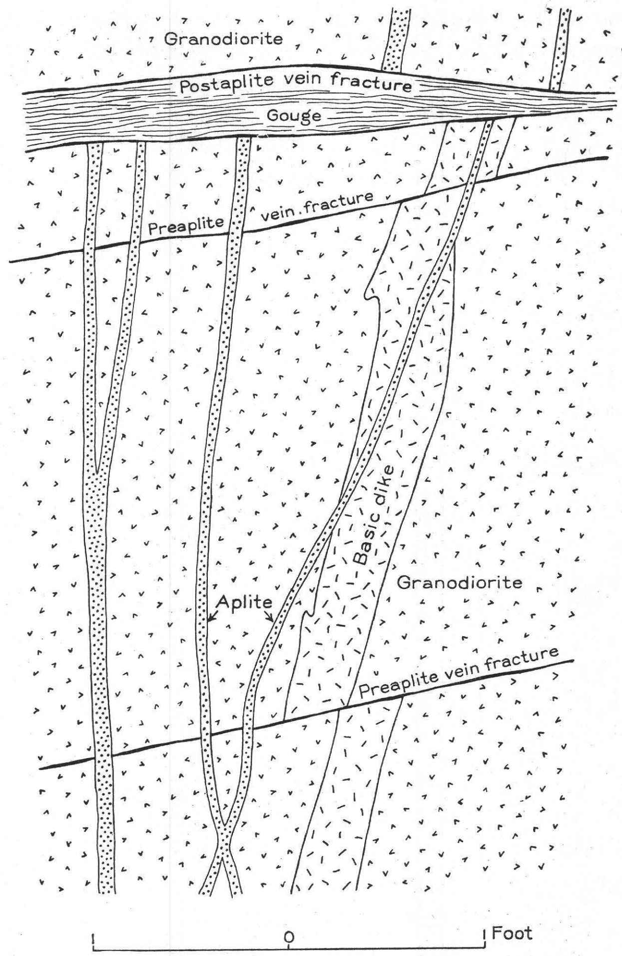


FIGURE 39.—Sketch of vein footwall on 7,200-foot level, North Star mine. The following sequence is shown: (1) Opening of steep northeastward-striking fractures (crossings?); (2) injection of basic dikes; (3) offset of dike along gently dipping northwestward-striking fracture (vein?); (4) opening of other steep northeastward-striking fractures (crossings?); (5) injection of aplite dikes; (6) offset of aplite dikes along gently dipping northwestward-striking vein fracture. A photograph of this exposure is shown in plate 24.

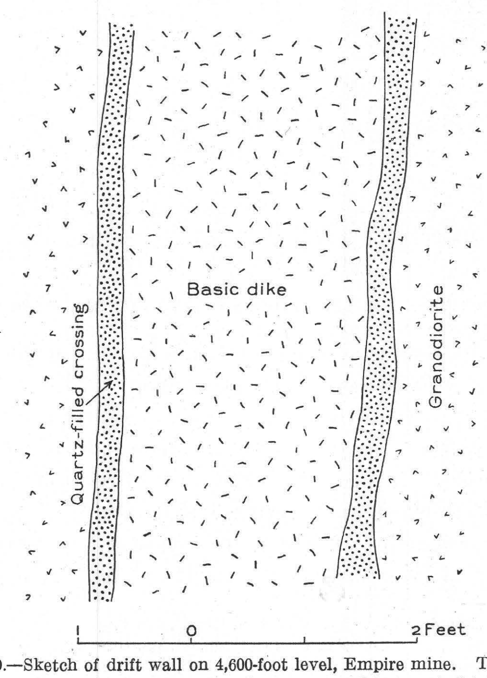


FIGURE 40.—Sketch of drift wall on 4,600-foot level, Empire mine. The following sequence is shown: (1) Opening of northeastward-striking vertical fracture (crossing?); (2) injection of basic dike; (3) reopening of vertical crossings on each side of dike; (4) filling by quartz.

[13] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 259.

From these and other underground exposures showing crosscutting relationships it can be established that—

1. Both gently dipping fractures of the vein type and steeply dipping northeastward-striking fractures of the crossing type were opened before the last of the post-granodiorite dikes were injected. Indeed, the preponderant strike of both basic and aplite dikes is to the northeast, like that of the crossings.

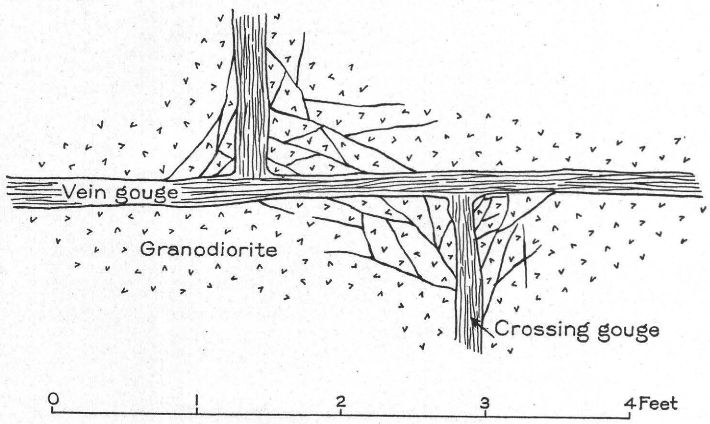


FIGURE 41.—Sketch of drift wall on 5,600-foot level, North Star mine, showing crossing offset on vein fracture.

2. Veins were offset along crossings and crossings along veins before quartz deposition began.

3. Both types of offsetting occurred during quartz deposition and continued after vein filling had ceased.

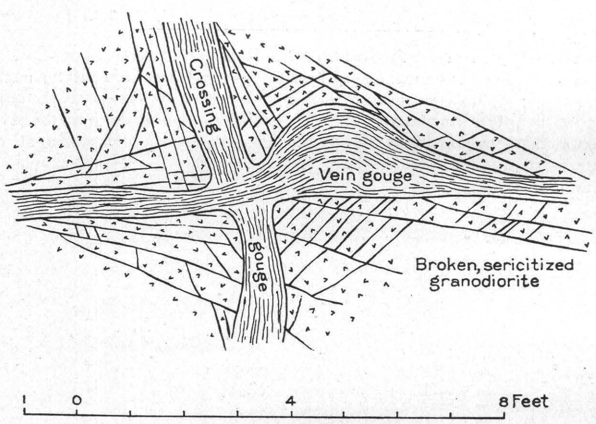


FIGURE 42.—Sketch of drift wall on 5,600-foot level of North Star mine, showing movement on the vein without offset of the crossing.

HYPOTHESES FOR THE ORIGIN OF THE FRACTURE SYSTEMS

Three hypotheses in explanation of the origin of the fracture systems have been advanced. In 1896 Lindgren [14] suggested that the fissure systems were of regional origin "produced by a succession of compressive stresses applied in different directions, chiefly from east to west and from north to south." Howe,[15] in 1924, regarded the fissure systems as structural elements of the intrusion itself. The crossings he believed to be closed, primary tension joints, and he regarded the vein fractures as thrust planes relieving the inward pressure of the host rocks when deep-seated withdrawal of granodiorite magma took place. This deep-seated withdrawal resulted, he believed, in the sagging of the solidified domed roof of intrusion and the closing of the tension cracks or crossings.

Johnston and Cloos,[16] in 1934, offered a third hypothesis. Like Howe, they believed that the vein systems were structural elements of the granodiorite intrusion, but they rejected the idea of a collapsed dome as unnecessary if the veins were regarded as marginal thrusts, developed in response to upward pressure of the deep plastic magma exercised on the solidified cupola. The crossings they regarded as of regional origin.

As none of these hypotheses appear to be wholly consistent with the evidence offered by the distribution of the veins and crossings and their structural sequence, they will be examined in some detail.

Hypothesis of regional compression.—The conjugated vein systems of the district strongly support Lindgren's hypothesis that the vein fractures are of regional dynamic origin, formed by compressive stresses. As the average dip of the veins is 35°, each conjugated pair of vein fractures in diabase or granodiorite makes a horizontal angle of about 70° and a vertical angle of about 110°. Bucher [17] formulated Hartmann's law [18] as follows: "In brittle materials the acute angle formed by the shearing planes is bisected by the axis of maximum compression, and the obtuse angle by the axis of minimum compression, which is generally negative, representing tension." This law, applied to the conjugated veins of the district, is in accord with the concept of lateral compression relieved upward.

"A succession of compressive stresses," even though "applied in different directions, chiefly from east to west and from north to south," does not adequately explain either the general parallelism of the veins to the granodiorite-diabase contact or the consistently northeastward-striking crossings.

Hypothesis of a collapsed arch.—Howe's hypothesis [19] takes recognition of the parallelism of the veins to the diabase-granodiorite contact and explains the crossings as tension cracks first opened by the intruding granodiorite. He says:

> It has been observed frequently that fractures occur in the upper portions of a batholithic intrusion and in the overlying rocks which have every appearance of having been brought about by tension due to the expanding force of the intrusion still in progress. When the force is spent and the consolidation of the granodiorite was in progress, a settling of the lower portions of

[14] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 170.

[15] Howe, Ernest, op. cit. (Econ. Geology, vol. 19), pp. 602–603.

[16] Johnston, W. D., Jr., and Cloos, Ernst, Structural history of the fracture systems at Grass Valley, Calif.: Econ. Geology, vol. 28, pp. 39–54, 1934.

[17] Bucher, W. H., The mechanical interpretation of joints: Jour. Geology, vol. 28, p. 712, 1920.

[18] Hartmann, L., Distribution des déformations dans les métaux soumis à des efforts, Paris, 1896.

[19] Howe, Ernest, op. cit., p. 602.

the intrusive is believed to have taken place. With the withdrawal of pressure from below, the arched roof of the new batholith would be closed. As a further result of the shrinkage or sagging, lateral pressure on the flanks would tend to force inward the invading rocks and the outer portion of the batholith, producing strains that would find relief in reverse faults of moderate throw and of lower angles of dip than the tension fissures first formed. The result of such movements would be systems of fissures such as are found in the Grass Valley district, dipping toward a central point. * * * It is further believed that the earlier-formed fissures of the tension type were, during the period in which the vein fissures were developed, closed and compressed and that slight differential movements of their walls may have taken place. The "crossings" * * * are regarded as belonging to this system of closed tension fissures.

Howe's hypothesis offers a reasonable explanation for both the conjugated vein systems and the parallelism of the veins to the diabase-granodiorite contacts. To account adequately for the crossings as tension joints, however, it is necessary to postulate that the roof was arched on an axis striking to the northeast, parallel to the strike of the crossings, whereas the long axis of the granodiorite body, the more likely axis of arching, strikes a little west of north.

Hypothesis of marginal thrusts.—In 1934 Johnston and Cloos [20] offered a synthesis of the structural history of the granodiorite. Because of the rarity of schlieren and the lack of oriented inclusions or phenocrysts in the granodiorite at Grass Valley, in contrast to the platy and linear flow structures that are found on the margins of the granodiorite at Nevada City, which they believe to have been eroded to a deeper horizon, the granodiorite at Grass Valley is pictured as a relatively small cupola of a greater intrusive mass where, as the static magma cooled, it passed from a state of viscosity to one of rigidity without great internal differential movement.

As long as the magma was fluid, pressure transmitted from below would be uniformly exerted on the wall and roof of the containing chamber. With the onset of consolidation, however, such hydrostatic adjustment was no longer possible, and during the stage of incipient rigidity, the continuing upward impulse of the intruding magma resulted in the opening of thrust fractures dipping into the intrusive. As the solidified magma has a rigidity comparable with that of the older rocks, the fractures developed in the granodiorite continue outward into the diabase and porphyrite host rocks. These adjustments of upward impulse from the magma, which began in the stage of incipient rigidity, continued into the rigid stage.

Thus they believed the vein fractures to be primary fractures in the strictest sense—fractures developed as a result of stresses imposed by the intrusive itself, although afterward the same fractures served for the adjustment of regional stresses. That they were not open in the early stage is inferred from the absence of marginal dikes with low dips.

[20] Johnston, W. D., Jr., and Cloos, Ernst, op. cit., pp. 39-54.

Following upon the incipient development of the vein fractures and before the last of the basic dike magma was exhausted, the earliest crossings were opened in response to regional stresses. The same regional stresses caused later movements on the vein-fracture system, accompanying or alternating with the opening of new crossings.

In contrast with Howe's hypothesis, which attributed the vein fractures to regional compression of an arched and unsupported dome, Johnston and Cloos regarded the vein fractures as elements of the internal tectonics of the intrusive body itself, originating in an early stage of the structural development of the region. The principal weakness of this hypothesis is that it fails to account for the veins that are conjugate to such "marginal thrusts" as the North Star and Empire veins except as normal faults or "planes of stretching" developed concurrently with the "marginal thrusts," which were subsequently reversed by later regional compression. Further difficulty is presented by the absence of dikes along nearly horizontal fractures of the vein system, as might be expected if the veins were opened earlier than the crossings.

Summary of hypotheses.—None of the hypotheses offer a wholly satisfactory explanation of the structural features. As both crossings and vein fractures are known to have opened before the dike magma was exhausted, they are both early structural elements. That regional stresses were active and recurrent in the later stages of vein filling is proved by reopened veins with crushed and broken quartz, and the reverse offsets on the veins that are measurable today are the net result of these later regional stresses. According to Lindgren's hypothesis the veins were formed as a result of similar earlier regional compressive stresses. Howe's hypothesis is in agreement with Lindgren's and has the added advantage of explaining the parallelism of the veins to the granodiorite-diabase contact. Much of the Johnston and Cloos hypothesis, as originally formulated, is untenable, for even though the veins that dip into the granodiorite may have originated as marginal thrusts, resulting from the upward and outward thrust of the granodiorite body, their principal development must have come as a result of later regional compressive stresses. Whether the crossings were formed by the stresses that produced the vein fractures or whether they had, to some degree, an independent tectonic history is an unsettled question.

METHOD OF VEIN FORMATION

SUMMARY OF OBSERVATIONAL EVIDENCE

Observational evidence bearing on the method of vein formation at Grass Valley is afforded by quartz textures, paragenesis of the vein minerals, vein structure, distribution of wall-rock inclusions, and wall-rock alteration. These lines of evidence will be briefly summarized.

As described on pages 40–42 the principal quartz textural types are comb quartz, massive milky hypidiomorphic quartz, sheared quartz, and brecciated quartz. Veins that have not undergone postquartz movement have comb quartz on the walls, recognizable by the preponderance of basal sections in thin sections cut parallel to the vein walls. A large number of underground exposures (pl. 9, *A*, *B*) point unmistakably to the fact that comb quartz represents the partial filling and massive milky quartz results from the complete filling of cavities. Postquartz movement results in sheared quartz when the interwall space is not appreciably dilated and brecciated quartz when the interwall space has been increased. These relations are summarized in the diagram on page 40.

A presumably high-temperature stage is represented by the pyrrhotite-magnetite-pyrite mineralization of the Crown Point mine and the specularite crossing in the Empire mine. The sulphides pyrite, arsenopyrite, sphalerite, and chalcopyrite were deposited with earlier quartz. With later quartz came galena and gold. Deposition of vein carbonates began after quartz deposition had almost ceased. Throughout the depositional interval there was recurrent movement of the vein walls.

Few of the veins are simple fractures filled with quartz "frozen" to both walls; most of them are in more or less complex fracture zones with many minor walls and with much interstitial broken country rock. The principal walls are commonly irregular surfaces with large grooves and ridges, and displacement in any direction would result in interwall cavities—some of considerable size. All veins pinch and swell along both dip and strike. Many show two or more generations of quartz, the younger quartz commonly crosscutting and healing fractures in the older quartz.

As shown in plates 8, *A*, *B*, *C*, and *D*; 9, *B*; and 10, *C* and *E*, wall-rock inclusions are abundant. Howe[21] has observed that where a vein crosses a contact the character of the inclusions changes at the same place that the wall rocks change, indicating that detached wall-rock fragments have not been swept along the vein fracture by either surging or buoyant or viscous solutions or melts.

Wall-rock alteration throughout the district has resulted in the formation of sericite, carbonates, and pyrite at the expense of all the primary rock minerals. The feldspars were most readily attacked, but even quartz has been replaced by sericite (pl. 5, *B*). Thus the principal chemical changes in the wall rock are the addition of carbon dioxide, potash, and sulphur and the removal of silica and sodium.

POSSIBLE HYPOTHESES

Any inquiry into the mechanism of vein formation at Grass Valley involves consideration of both the medium by which quartz was transported and from which it was deposited, and the method of its deposition. The source of the vein material is considered under a later heading. The various hypotheses which, from time to time, have been advanced, can be presented in outline form.

Possible media of quartz transportation and deposition:
1. Relatively dry siliceous melts.
2. Colloidal silica gels.
3. Vapor phase.
4. Aqueous solutions.

Possible methods by which quartz veins were formed:
1. Filling open fissures.
2. Opening and enlarging closed fissures by—
    a. Telluric pressure.
    b. Force of growing crystals.
    c. Replacement of the vein walls.

Of these possibilities, Lindgren's hypothesis that the veins were formed by deposition from aqueous solutions in open fissures appears to be more nearly in accord with observed data. The various hypotheses are examined below in some detail.

HYPOTHESES FOR TRANSPORTATION AND DEPOSITION OF QUARTZ

Deposition from relatively dry siliceous melts.—The belief, stimulated by Spurr's book of 1923,[22] that the quartz veins were deposited from silica melts differing only from the aplite melts in the presence of ore minerals and a somewhat greater proportion of water, is widely held in the district. The arguments most commonly advanced in support of this hypothesis are as follows:

1. The presence of "unsupported" inclusions of wall rock in the veins indicates that the depositing medium was either dense enough to float the fragments or viscous enough to support them.

2. The sharpness of the contact between vein material and wall rock and the absence of replacement of wall rock by quartz indicate that the quartz was deposited from a medium too viscous to penetrate between the constituent mineral grains of the wall rock.

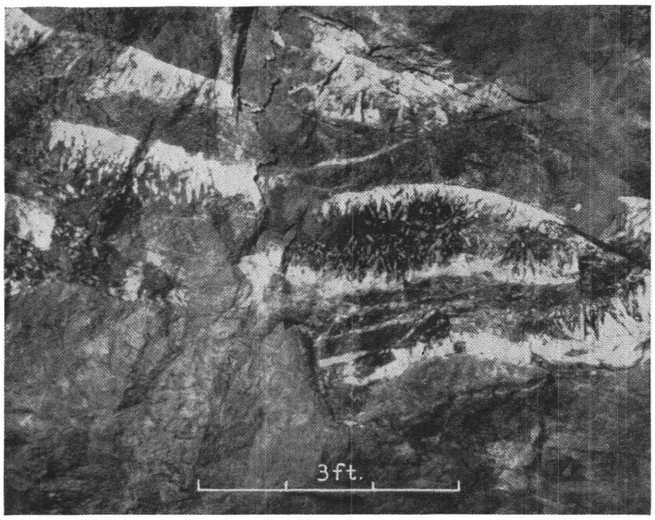
That "unsupported" inclusions are generally unsupported only in the plane of the exposed section was admirably shown by Talmage.[23] He filled a box with variously shaped pieces of colored soap, representing inclusions, in such a way that the top pieces rested on and were supported by the bottom pieces. Around these soap fragments he poured melted Crisco, a vegetable fat, representing the quartz matrix. When cool the model was sectioned, and most of the inclusions were "unsupported" in the plane of the section. He concluded [24] that "The theory of viscous support must stand or fall on physicochemical grounds; it can derive no confirmation from patterns of angular apparently 'unsupported' inclusions."

[21] Howe, Ernest, op. cit. (Econ. Geology, vol. 19), p. 613.

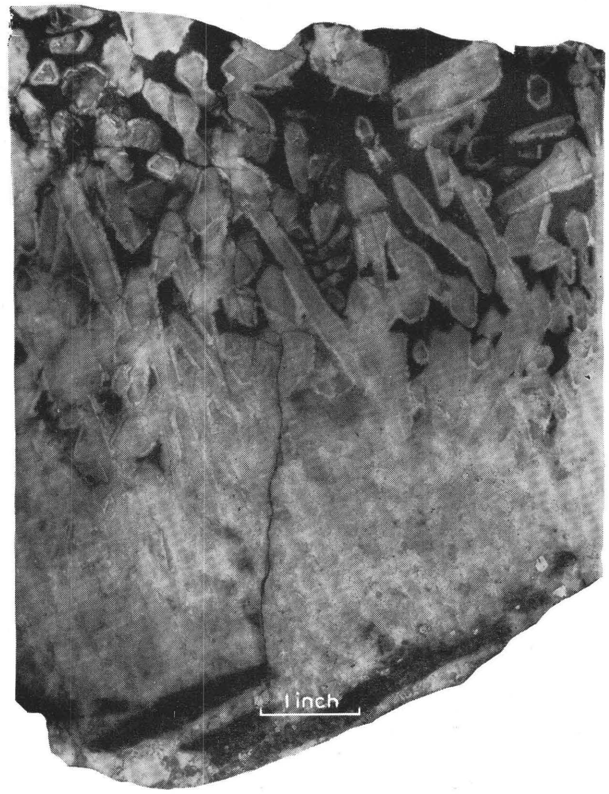
[22] Spurr, J. E., The ore magmas, 2 vols., New York, McGraw-Hill, 1923.

[23] Talmage, S. B., The significance of "unsupported" inclusions: Econ. Geology vol. 24, pp. 601–610, 1929.

[24] Idem, p. 609.

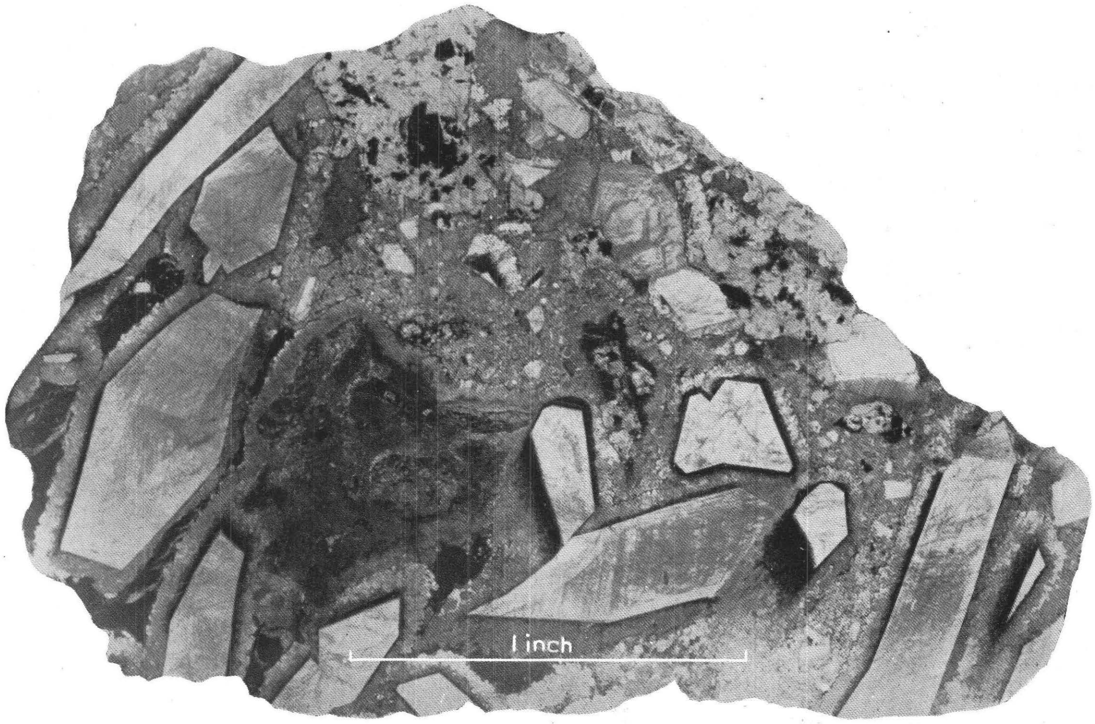


A. VUG IN VEIN, NORTH STAR MINE, NO. 2 VEIN, 6,300-FOOT LEVEL.



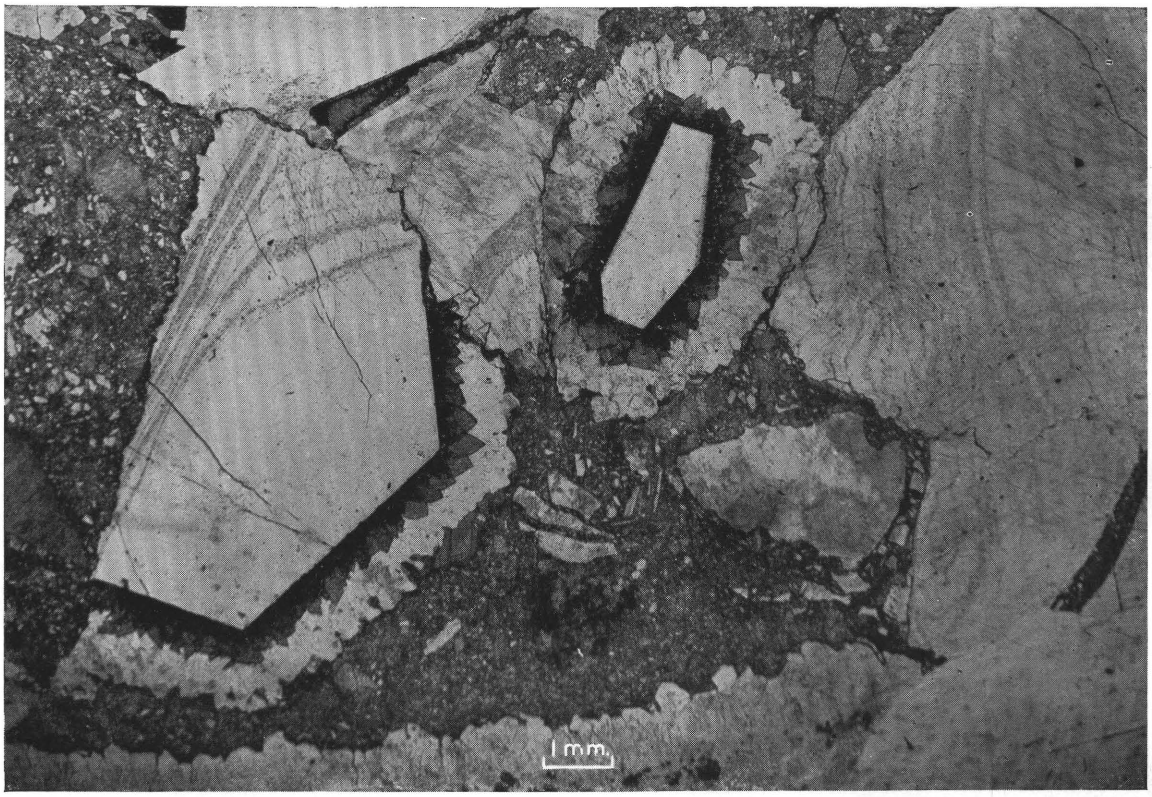
B. POLISHED SLAB FROM THE VUG SHOWN IN *A*.

Euhedral quartz crystals are coated with white ankerite. The vug is filled with a dark-green mixture of chlorite and mechanically ground quartz in a matrix of carbonates.



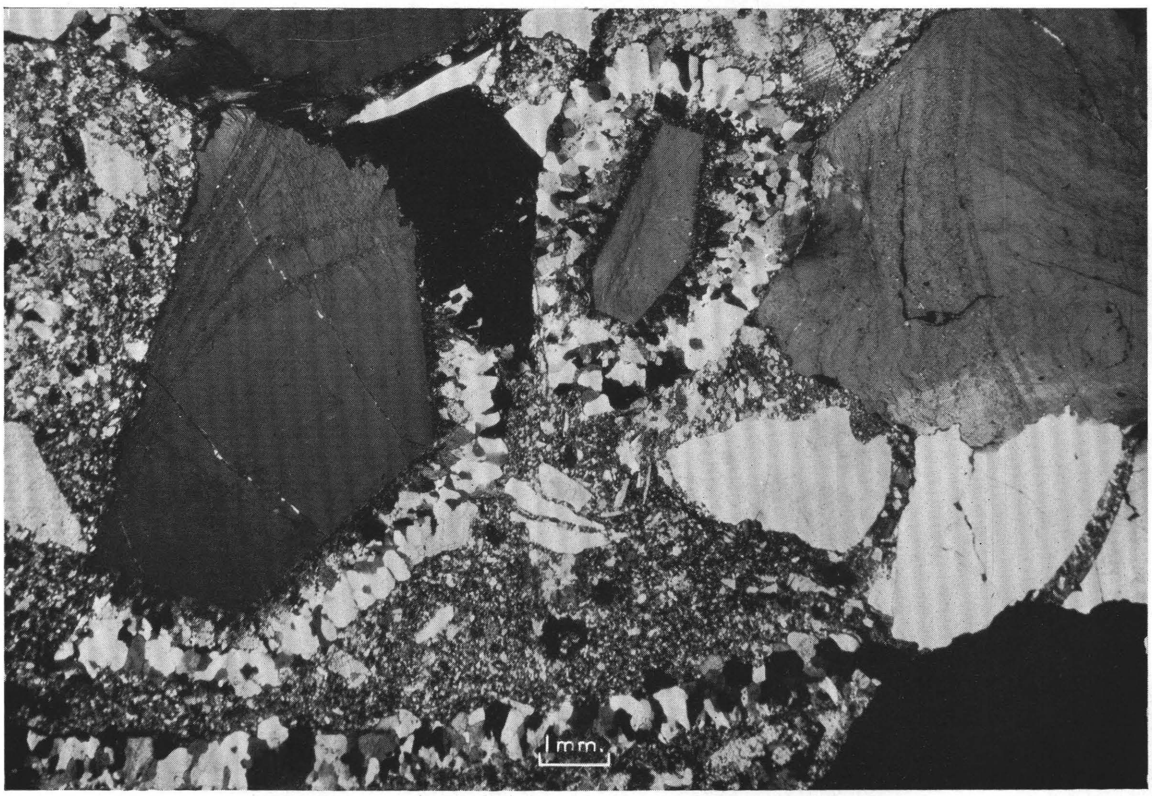
C. THIN SECTION FROM VUG SHOWN IN *A*, SHOWING EUHEDRAL QUARTZ, CHLORITE, AND CARBONATES.

VUGS AND COMB QUARTZ.



A. THIN SECTION OF VUG FILLING SHOWN IN PLATE 15.

Euhedral quartz is surrounded by a vein of ankerite (dark) and a vein of smaller quartz combs (light). At that stage the vug lining was disturbed, and some of the euhedral quartz crystals were broken. Finally a mixture of chlorite and mechanically ground quartz cemented by ankerite filled the entire vug and formed a matrix around the earlier combs. North Star mine, No. 2 vein, 6,300-foot level. Plain light.

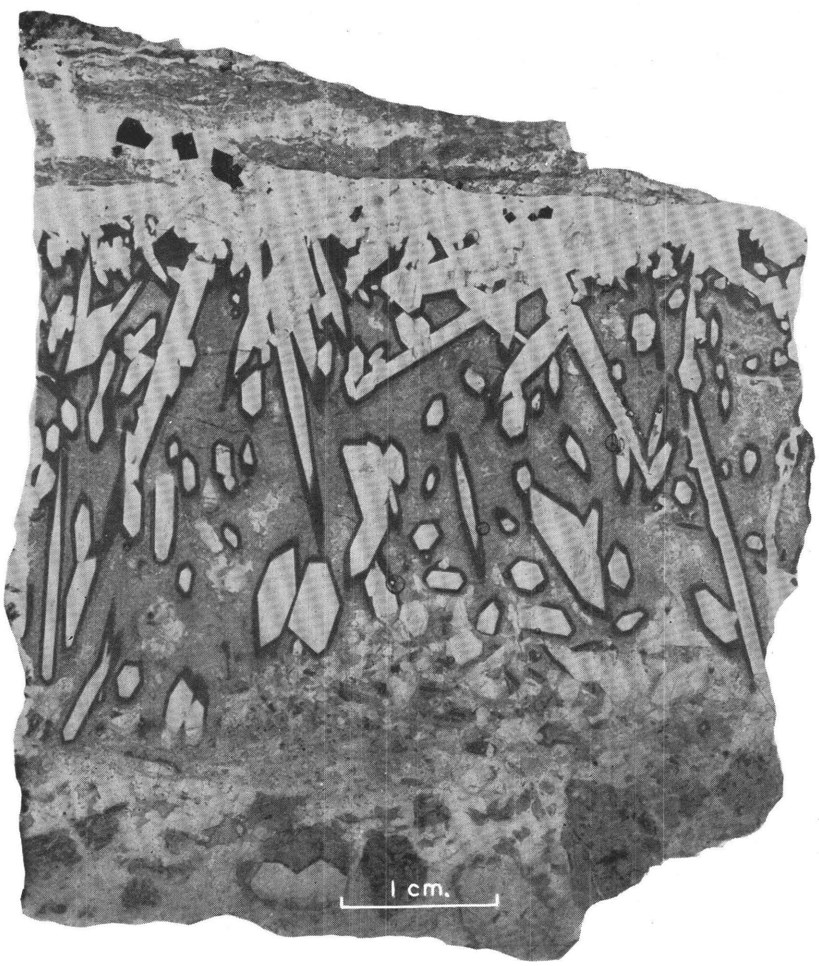


B. SAME AS *A* BUT WITH CROSSED NICOLS.

DETAILS OF VUG LINING.

A. POLISHED SLAB SHOWING BOTH COMB AND SHEARED QUARTZ.

Ankerite forms a matrix for the quartz combs. The dark areas in the lower part of the specimen are inclusions of granodiorite which are largely replaced by ankerite, chlorite, and sericite, but not by quartz. North Star mine, No. 2 vein, 8,600-foot level.



B. THIN SECTION OF UPPER PART OF SLAB SHOWN IN *A*.

It shows clear euhedral quartz surrounded by a dark rim of fine-grained ankerite and all interstices filled with coarser-grained ankerite. The lower part of the section shows older sheared quartz with a little ankerite. Black polygons in clear quartz near top of section are pyrite.

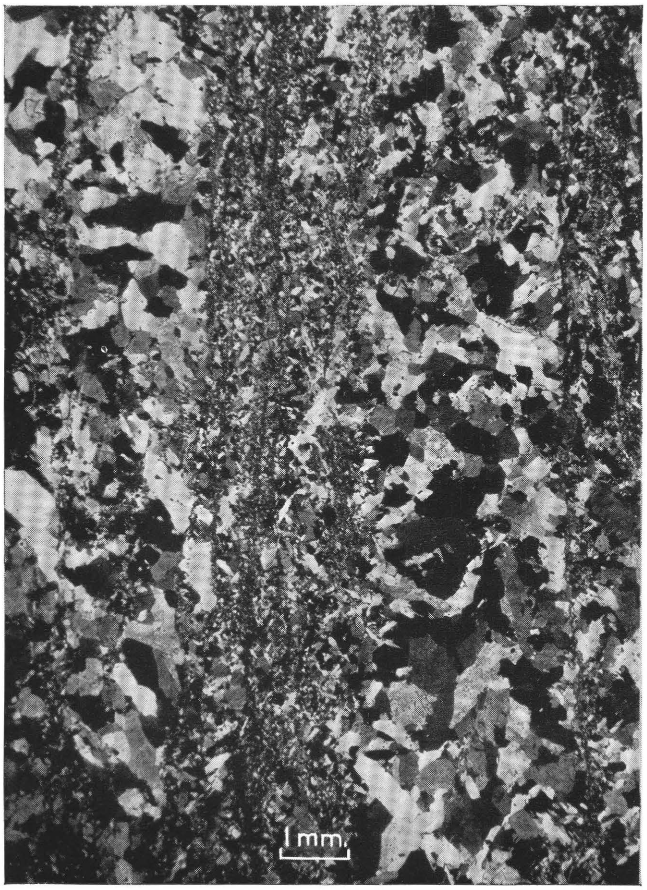
COMB AND SHEARED QUARTZ.

A

B

COMB QUARTZ AND CARBONATES.

A. Polished section of vein composed of quartz and carbonates. North Star mine, No. 2 vein, 8,600-foot level. *B*. Same section with carbonates dissolved by hydrochloric acid. The quartz shows comb structure and cavities which existed prior to the introduction of the carbonates. *A* and *B* are opposite saw-cut faces of the same specimen.

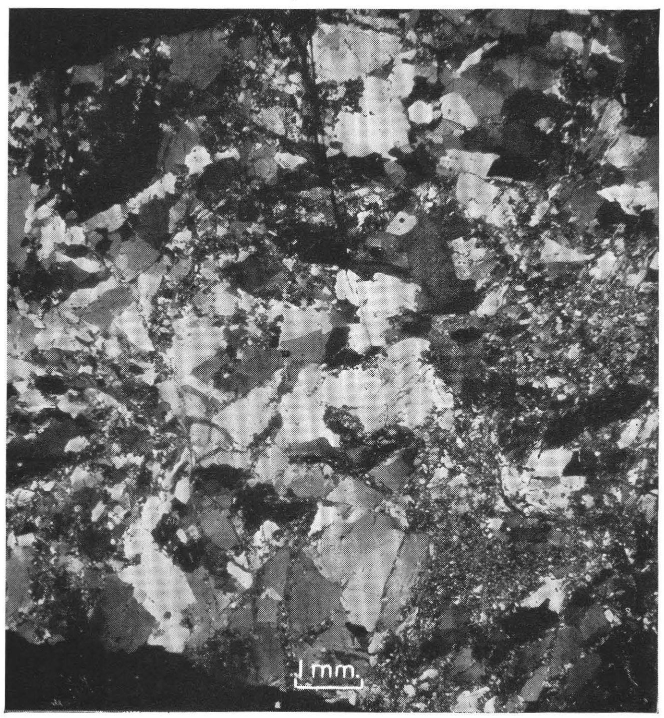


A. GRANULATION ZONES PARALLEL TO VEIN WALLS.

Gold occurs in the zones of granulation. Pennsylvania mine, 1,100-foot level. Crossed nicols.

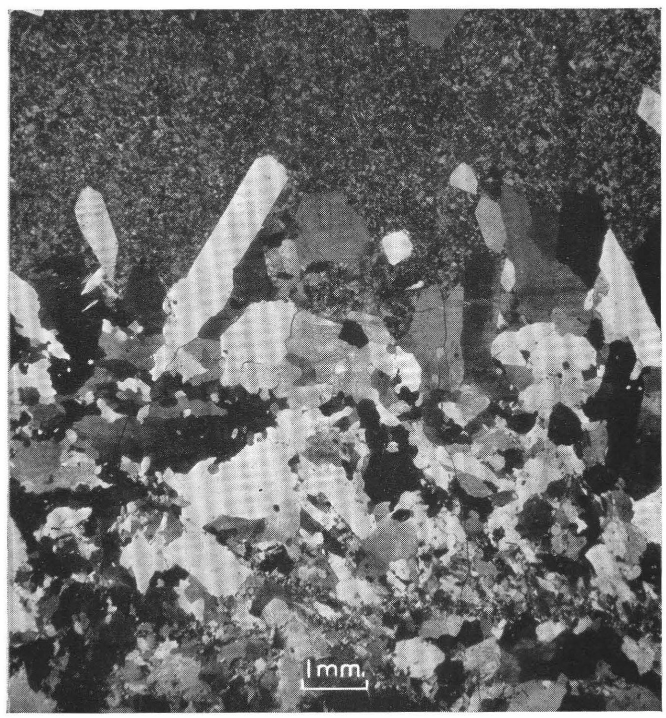
B. IRREGULAR GRANULATION ZONES.

Note strain lines in the larger quartz grains. Empire mine, 4.600-foot level. Crossed nicols.



C. IRREGULAR GRANULATION WITH DEVELOPMENT OF MORTAR STRUCTURE.

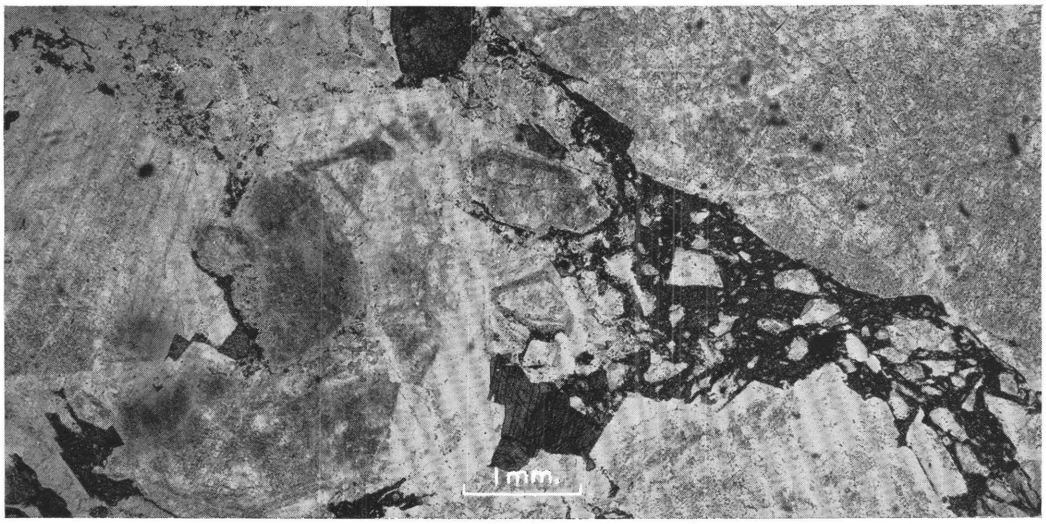
North Star mine, No. 2 vein, 8,200-foot level. Crossed nicols.



D. COMB QUARTZ GRANULATED ALONG THE VEIN WALL.

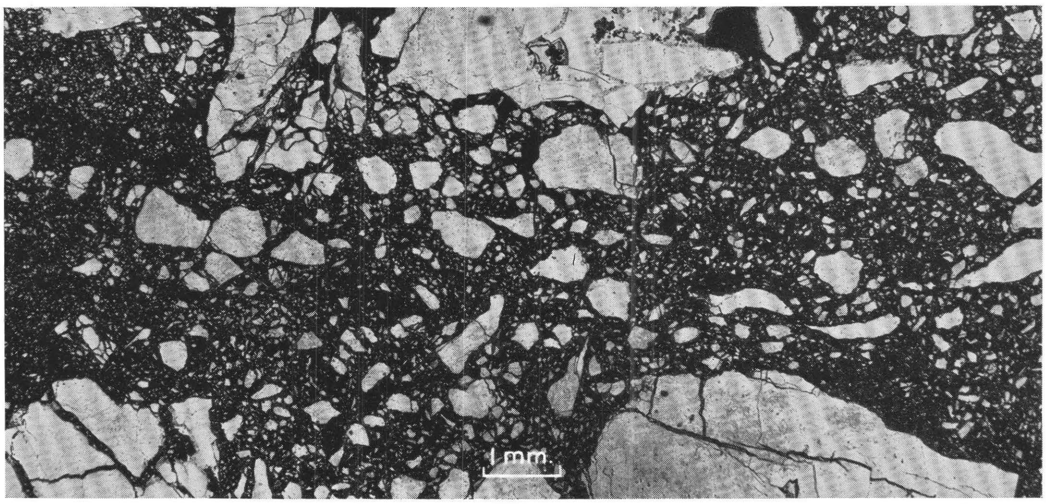
Fine-grained material at top of section is ankerite. Thin section shows the development of sheared textures from comb quartz. North Star mine, No. 3 vein, 9,000-foot level. Crossed nicols.

PHOTOMICROGRAPHS OF SHEARED QUARTZ.



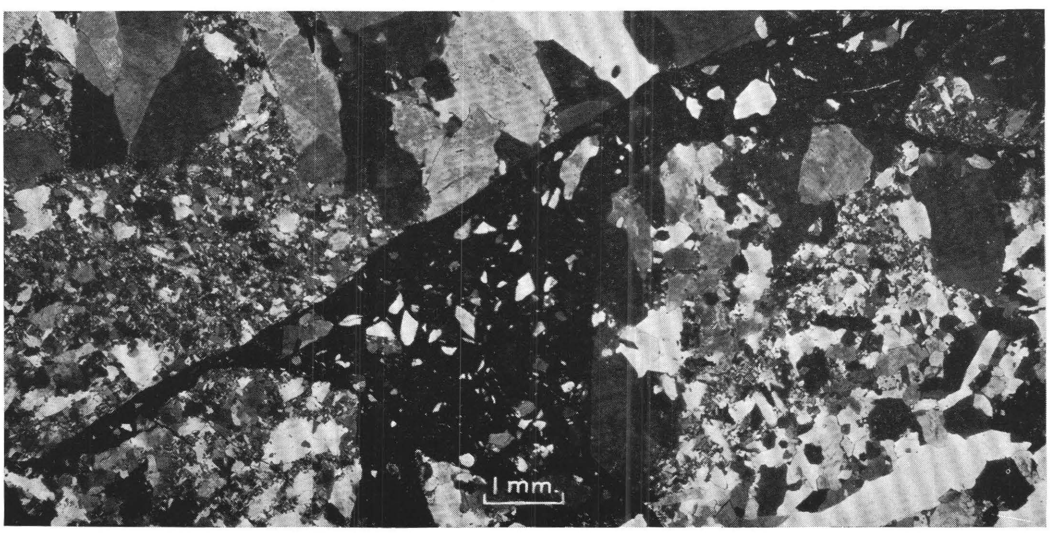
A. BRECCIATED QUARTZ CEMENTED BY ANKERITE.

The black dots in the clear quartz are vacuoles. Empire mine, Newmont vein, 3,800-foot level. One nicol.



B. BRECCIATED QUARTZ CEMENTED BY CHALCEDONY.

In the large quartz area at the top center are two small vugs lined with clear opal. Golden Center mine, Sleep vein, 500-foot level. One nicol.



C. BRECCIATED QUARTZ CEMENTED BY LIMONITIC CHALCEDONY (BLACK).

An earlier zone of shearing is marked by the fine-grained quartz. Empire mine, 1,300-foot level. Crossed nicols.

PHOTOMICROGRAPHS OF BRECCIATED QUARTZ.

A. ANKERITE VEINLETS CUTTING SMALL QUARTZ VEIN AND EXTENDING INTO THE WALL ROCK.

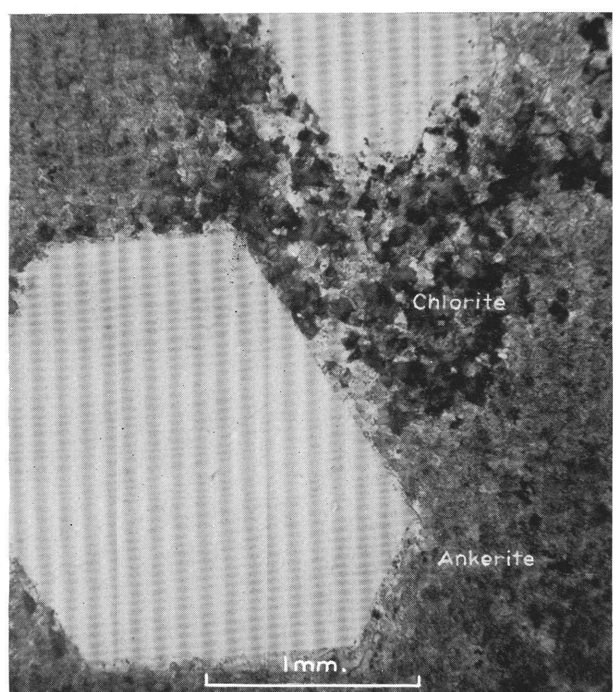
Empire mine, 2,700-foot level. Plain light.

B. QUARTZ WITH MARGINAL ZONES OF VACUOLES PARALLEL TO PRISM FACES.

In the interior of the crystals the lines of vacuoles are independent of crystallographic direction. In the upper part of the section sericite is replacing quartz. North Star mine, No. 1 shaft, below 7,850-foot station. Plain light.

C. BASAL SECTION OF QUARTZ CRYSTAL SHOWING ZONES OF VACUOLES.

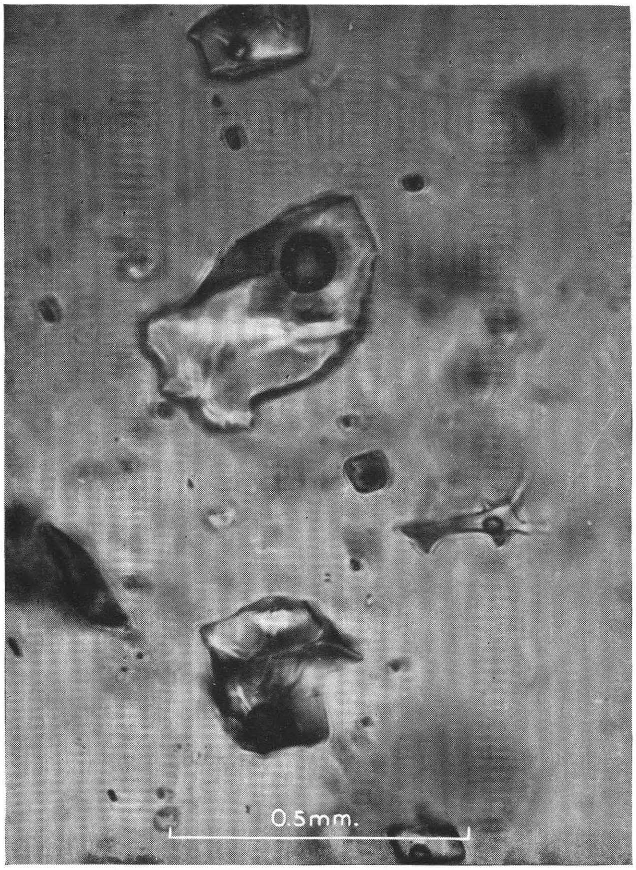
Empire mine, 5,000-foot level. Plain light.



D. EUHEDRAL QUARTZ SURROUNDED BY FINE-GRAINED ANKERITE AND CHLORITE.

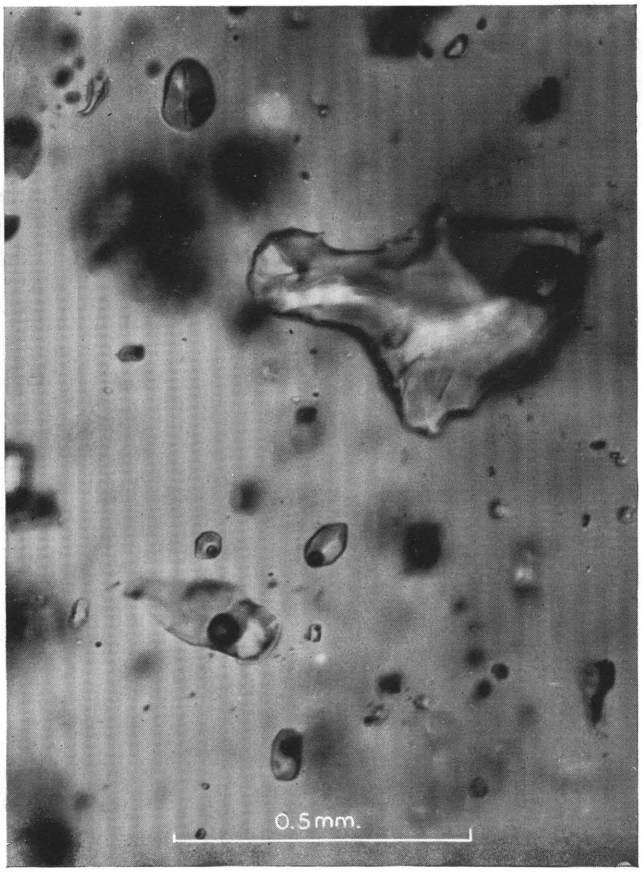
Empire mine, 7,000-foot level. Plain light.

PHOTOMICROGRAPHS SHOWING ZONED ENCLOSURES AND VACUOLES.



A. VACUOLES IN VEIN QUARTZ WITH OCCLUDED LIQUID CONTAINING GAS BUBBLES.

North Star mine, No. 2 vein, 6,900-foot level.



B. ANOTHER THIN SECTION FROM SAME SPECIMEN AS *A.*

A negative crystal appears in the center.

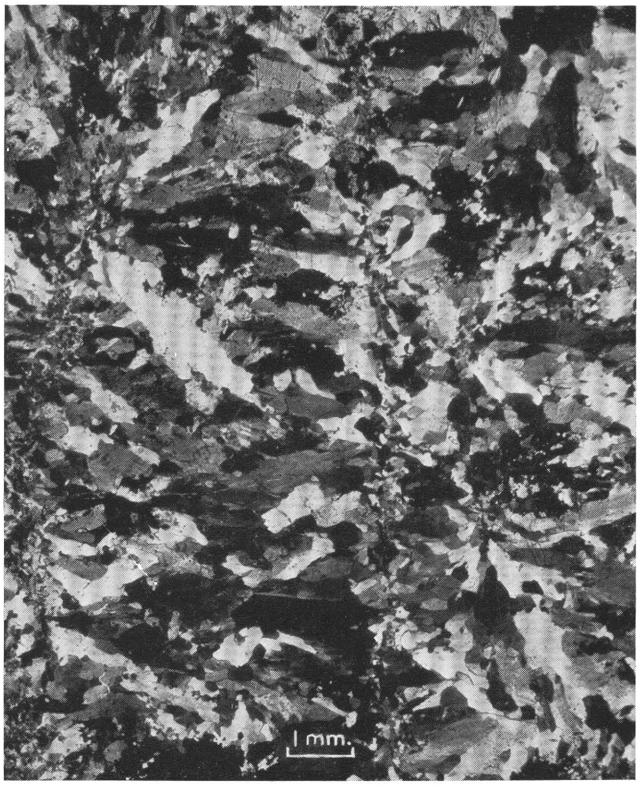
C. PHANTOM VEINLETS OF CLEAR QUARTZ CUTTING EARLIER QUARTZ CLOUDED BY VACUOLES AND INCLUSIONS.

One nicol.

D. SAME AS *A.*

The quartz in the phantom veinlets has the same optic orientation as the crystals it cuts. Crossed nicols.

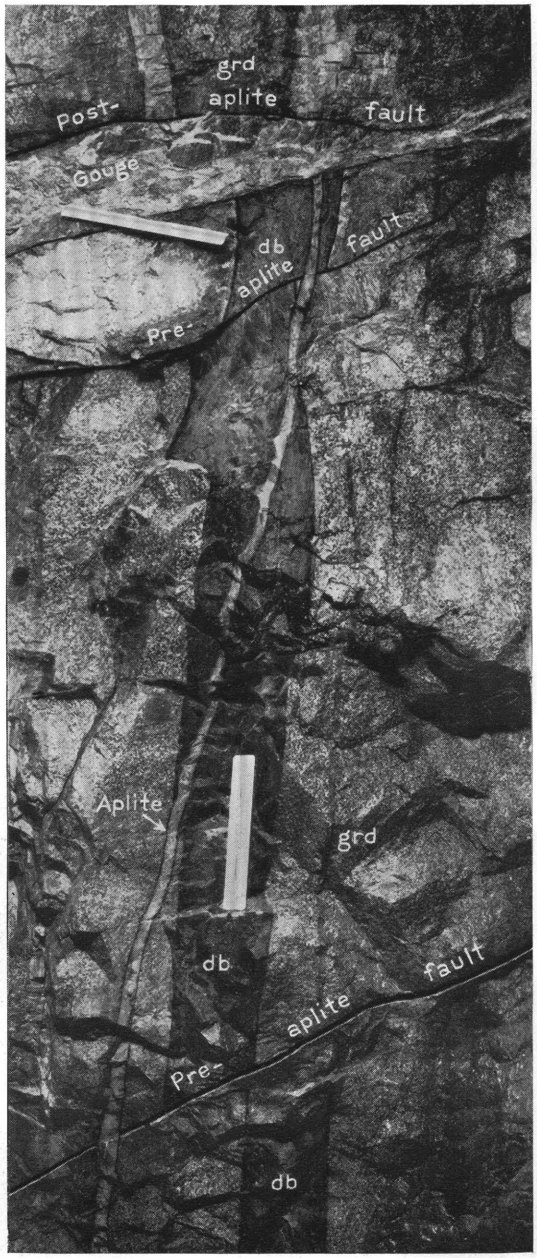
VACUOLES AND PHANTOM VEINLETS.



A. FEATHER QUARTZ IN CROSSING.
Empire mine, 3,000-foot level, south drift. Crossed nicols.

B. FEATHER QUARTZ IN CROSSING.
Empire mine, 4,600-foot level, short drift on crosscut to X vein. Crossed nicols.

FEATHER QUARTZ.



UNDERGROUND PHOTOGRAPH OF THE INTERSECTION OF BASIC (DB) AND APLITE DIKES IN GRANODIORITE (GRD) THAT HAVE BEEN FAULTED BY VEIN FRACTURE.

North Star mine, 7,200-foot level. (See fig. 39.)

Howe [25] in discussing the question says:

> The conception of the veins as intrusives implies comparatively rapid movement on the part of the invading magma. If this be true, the included fragments of wall rock in considerable numbers would be swept beyond those parts of the vein walls from which they were detached. This is a point difficult to prove or disprove, but where the North Star vein passes from between walls of granodiorite into the overlying diabase-porphyrite it has been found that fragments of granodiorite included in the quartz end abruptly and that above the contact only diabase-porphyrite inclusions occur.

My own observations on several other veins at the granodiorite contact are in conformity with those of Howe.

Farmin, [26] however, has described several underground exposures in the Idaho-Maryland, Brunswick, and Spring Hill mines where the vein inclusions are lithologically dissimilar to the adjacent wall rock. The displacement of the inclusions, he believes, cannot be explained by faulting but is "easily explained by surgence of the vein-forming solution, especially if it is thought to be a comparatively concentrated one, from which the more volatile fractions either escape during crystallization to alter the wall rock or remain behind as fluids in vugs and vacuoles."

That veins have been reopened and more than one generation of quartz deposited is evident in many underground exposures (pl. 8, *C*). With each reopening there is opportunity for detached fragments of wall rock to fall on a quartz footwall and be included in the vein as "unsupported" inclusions by later quartz deposited above and around them.

The fact that quartz does not replace minerals of the wall rock tells little regarding the viscosity or tenuousness of the vein-depositing medium. It suggests either that the medium was saturated with regard to the mineral constituents of the wall rock and so did not dissolve them, or that the fissure was so open and the wall rock so impervious that no penetration of the wall rock took place.

It is difficult to visualize the physical and chemical character of an "ore magma" from which quartz of the textural types found at Grass Valley would be deposited.

Deposition from colloidal silica gels.—There are few or no observational data at Grass Valley indicating that the quartz was injected as a silica gel in the manner suggested by Boydell.[27] Although chalcedony, which is commonly supposed to represent a gel, is one of the vein minerals (pls. 13, *E*, 20, *B* and *C*) it is not abundant, and it generally cements earlier quartz breccias; furthermore, opal, another gel product, is very rare (pl. 20, *B*). No evidence of diffusion banding or other structures suggesting original deposition from gels followed by dehydration and shrinkage were observed. On the other hand, it is difficult to regard the abundant comb quartz with individual euhedral crystals as much as 3 inches in length as having crystallized in and from a stiff hydrous silica gel. Likewise the zoned inclusions and vacuoles in many quartz crystals (pl. 21, *B* and *C*) can better be explained by growth from an aqueous solution.

Deposition from the vapor phase.—Unlike Spurr's hypothesis of ore magmas or Boydell's of colloidal solutions, the hypothesis that quartz veins were formed by the volatile transport of silica has lacked a champion. Morey [28] in a series of experiments in 1932 found that silica was not transported by steam at temperatures of 415° C. maintained for 24 days or 490° C. maintained for 5 days. Greig, Merwin, and Shepherd [29] found that the volatile transportation was accomplished at temperatures of 1,175° to 1,200° C. in the presence of water vapor and the silica was deposited as cristobalite. As all the vein quartz at Grass Valley is of the low-temperature variety that must have crystallized below 573° C., the fact that transportation of silica can be accomplished at high temperatures is of little help in establishing deposition of the quartz veins from the vapor phase. At Grass Valley no evidence for this process of transportation and deposition was observed. It is of interest to note that Lindgren [30] rejected as the alternative to aqueous deposition "an origin by sublimation or by gaseous emanation."

Deposition from aqueous solutions.—The principal reason for the foregoing consideration of hypotheses alternative to that of deposition from aqueous solutions lies in the fact that each hypothesis has its advocates among the miners of the district, and sharp differences of opinion arise in friendly speculations on the ever-fascinating subject of how the veins were formed.

Lindgren made out a strong case for the aqueous-solution hypothesis, not only for the veins of Grass Valley and Nevada City [31] but for other districts [32] in the Sierra Nevada as well, and all the observational data obtained in the present study confirm his belief.

Euhedral quartz crystals normal to the vein walls (pls. 17 and 18), vugs lined with comb quartz (pls. 15 and 16), and combs in wide veins showing transitions into the dense milky quartz that is so characteristic of the district (pl. 9, *A* and *B*) are more readily conceived as growing from an aqueous solution than from a relatively dry melt, a gel, or a vapor phase. Similarly, zonally arranged inclusions and vacuoles (pl. 21, *B* and *C*), many of which contain liquid (pl. 22, *A* and *B*) that may have been trapped from the quartz-depositing

[25] Howe, Ernest, op. cit., p. 613.

[26] Farmin, Rollin, Dislocated inclusions in gold quartz veins at Grass Valley, Calif.: Econ. Geology, vol. 33, pp. 579–599, 1938. Discussion by W. A. Wiebenga, idem, vol. 34, pp. 343–346, 1939.

[27] Boydell, H. C., The role of colloidal solutions in the formation of mineral deposits: Inst. Min. and Metallurgy [London] Trans., vol. 34, pt. 1, pp. 145–337, 1925.

[28] Morey, G. W., The volatility of silica with steam: Am. Geophys. Union Trans., vol. 13, p. 269–270, 1932.

[29] Greig, J. W., Merwin, H. E., and Shepherd, E. S., Notes on the volatile transport of silica: Am. Jour. Sci., 5th ser., vol. 25, pp. 61–73, 1933.

[30] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 172.

[31] Idem, p. 172.

[32] Lindgren, Waldemar, Characteristic features of California gold quartz veins: Geol. Soc. America Bull., vol. 6, pp. 221–240, 1895.

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solutions, are difficult to explain in any other way. If the deposition of the comb and dense milky quartz from aqueous solutions is granted, the development of other textures by mechanical deformation of these depositional types, as discussed on pages 40–42, offers little difficulty.

Lindgren [33] obtained what is probably direct evidence of the chemical character of the vein-depositing solutions by crushing vacuole-filled quartz, leaching it to remove soluble material, presumably mainly the contents of the vacuoles, and analyzing the leaching water. As given in more detail on page 42, he found that the filtrate contained mainly SiO_2, CaO, $(K, Na)_2O$ and SiO_3 to the amount of 187 grams to the ton of quartz. Because it is by no means certain that all the substances revealed in the analyses were originally present in the liquid of the vacuoles, and because certain gaseous constituents may have escaped during the crushing of the quartz, this experiment is not positive proof of the character of the vein-depositing solutions, but it is significant that the substances found are those which, from the character of the wall-rock alteration adjacent to the veins, might be expected to be present in those solutions. However, George Steiger,[34] who made the original analyses, expressed the opinion that some of the silica reported might have been dissolved from the finely ground quartz and not have come from the vacuoles.

The abundance of carbonates, sericite, and pyrite in the wall rocks adjacent to the veins indicates that those minerals were deposited from solution that proceeded from the vein fractures along which the circulation of solutions rich in carbon dioxide, potassium, and sulphur took place. As a result of this replacement the wall rocks lost silica.

As the carbonates and most of the sericite of the veins are later than most of the quartz, it appears evident that two types of solutions were active—an earlier one from which the vein quartz was deposited, and a later one which deposited the carbonates and sericite. It appears most probable that only this later solution penetrated and appreciably replaced the wall rocks adjacent to the veins.

The change from solutions depositing quartz to those depositing carbonates was pulsatory, as is witnessed by alternate deposition of quartz and ankerite in vugs (pl. 16). The analyses of mine waters (fig. 10) tell nothing about the character of the vein-depositing solutions, as present-day waters are of meteoric origin and their chemical character is determined by the rocks through which they pass.

MECHANISM OF QUARTZ DEPOSITION

All the observed evidence points toward the deposition of quartz from aqueous solution, and fissure filling appears to be the sole mechanism of vein formation. Alternative to filling of open fissures is the enlargement of closed fissures by (1) telluric pressure, (2) the force exerted by growing crystals, or (3) the replacement of the vein walls.

The hypothesis that the solutions depositing quartz were under sufficient pressure to force aside the walls of closed fissures against the confining pressure of the overburdening rocks is difficult to accept, for if the solutions were under such pressure they would be forced upward through the crossings, many of which are open and would furnish more ready egress than the veins. Furthermore, it is extremely difficult to conceive of solutions under such pressure and at the same time incapable of penetrating and silicifying the wall rocks, a process that has not been operative at Grass Valley.

It has been shown experimentally that growing crystals exert a pressure on the medium which confines them,[35] and Taber [36] has suggested that some quartz veins were formed by quartz crystals shoving apart the vein walls as they grew. In his papers on frost heaving [37] he has demonstrated the effectiveness of this process by growing ice crystals which opened veinlike cracks in clay cylinders against confining pressures as great as 14 kilograms per centimeter. All these cracks, however, were filled by cross-fiber ice crystals, a fact which strongly confirms the contention of Howe [38] and of Ferguson [39] that quartz veins formed by this process would show a tendency toward cross-fiber structure, with parallel development of greatly elongated quartz crystals perpendicular to the vein walls. While comb structure is common in the Grass Valley veins, it rarely extends across even small veins but is confined to the walls or to vug linings, and its pattern does not suggest cross-fiber structure. The large amount of sheared and brecciated quartz in the veins points toward a vein filling that yielded in response to wall stresses rather than one that originated such stresses.

Howe [40] believed that "the veins were formed by the replacement of wall rock by quartz, calcite, and metallic sulphides and that subsequent fracturing of the vein filling permitted the introduction of later solutions which deposited the gold." All who have studied the district agree that carbonates, sericite, and pyrite have replaced the wall rock, but evidence for replacement by quartz is lacking. Lindgren [41] observed that "replacement by silica is not among the processes here recognized." Howe [42] stated that "metasomatic quartz has

[33] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), pp. 130–131.

[34] Oral communication, 1933.

[35] Becker, G. F., and Day, A. L., The linear force of growing crystals: Washington Acad. Sci. Proc., vol. 7, pp. 282–288, 1905.

[36] Taber, Stephen, Pressure phenomena accompanying the growth of crystals: Nat. Acad. Sci. Proc., vol. 3, pp. 297–302, 1917; Origin of the Bendigo quartz veins: Econ. Geology, vol. 13, pp. 538–546, 1918; Mechanics of vein formation: Am. Inst. Min. Eng. Trans., vol. 61, pp. 3–36, 1919; Metasomatism and the pressure of growing crystals: Econ. Geology, vol. 21, pp. 717–27, 1926; The linear force of growing crystals: Econ. Geology, vol. 23, pp. 335–336, 1928.

[37] Taber, Stephen, The mechanics of frost heaving: Jour. Geology, vol. 38, pp. 314–315, 1930.

[38] Howe, Ernest, op. cit. (Econ. Geology, vol. 19), p. 610.

[39] Ferguson, H. G., and Gannett, R. W., op. cit. (Prof. Paper 172), p. 82.

[40] Howe, Ernest, op. cit., p. 619.

[41] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 147.

[42] Howe, Ernest, op. cit., p. 615.

not been recognized as one of the minerals replacing the granodiorite or diabase," and no evidence for replacement of wall rock by quartz was observed in the present investigation. Rather than being replaced by quartz, the wall rocks have lost silica, owing to the replacement of silicates by carbonates and pyrite. Howe's principal lines of evidence for replacement were unsupported inclusions and shattered and feathering vein-segment junctions (pl. 10, *C*). The significance of unsupported

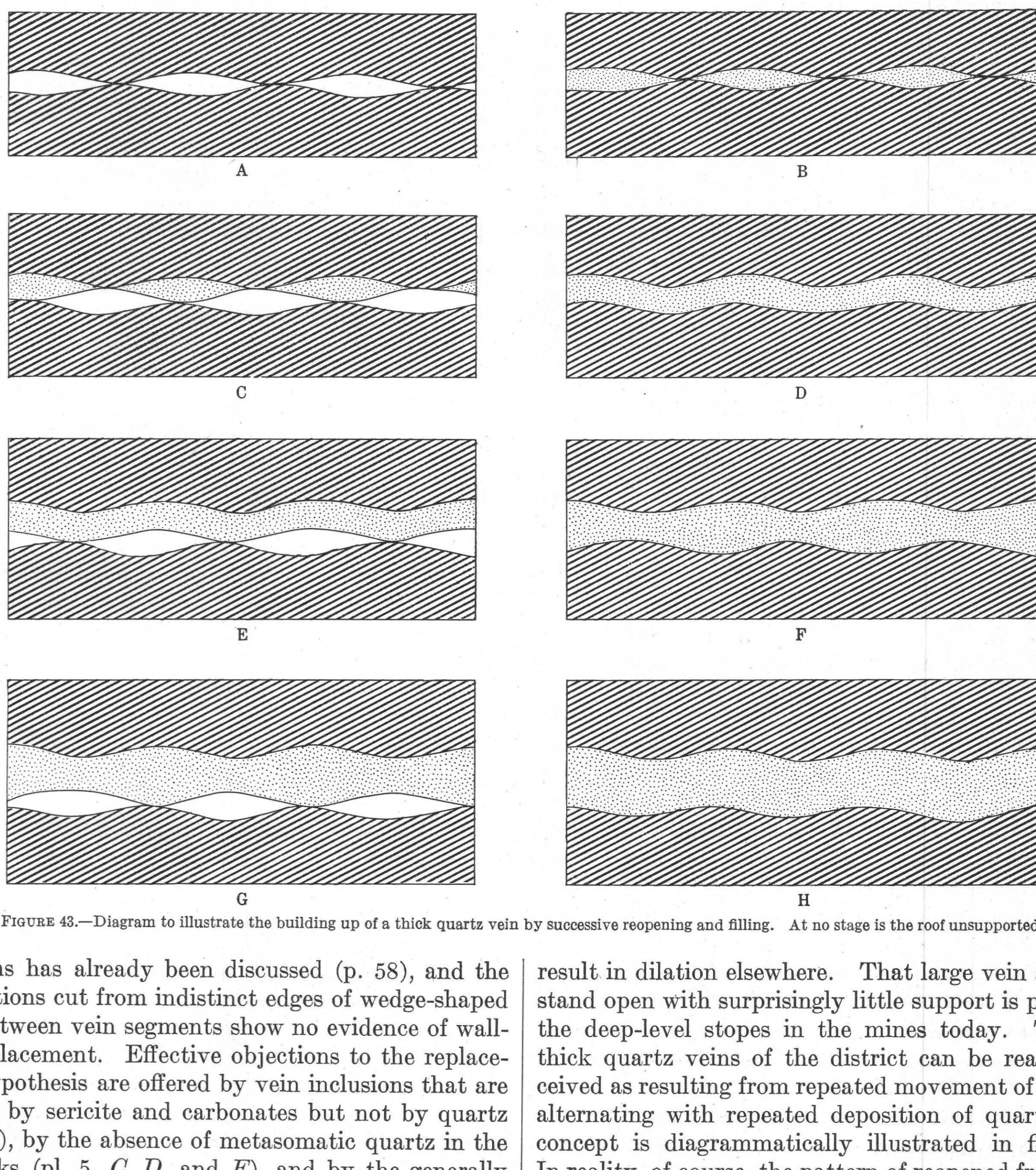


FIGURE 43.—Diagram to illustrate the building up of a thick quartz vein by successive reopening and filling. At no stage is the roof unsupported.

inclusions has already been discussed (p. 58), and the thin sections cut from indistinct edges of wedge-shaped septa between vein segments show no evidence of wall-rock replacement. Effective objections to the replacement hypothesis are offered by vein inclusions that are replaced by sericite and carbonates but not by quartz (pl. 8, *B*), by the absence of metasomatic quartz in the wall rocks (pl. 5, *C, D,* and *E*), and by the generally sharp vein walls (pl. 8).

The formation of quartz veins by deposition in open fissures, as suggested by Lindgren,[43] is in agreement with the observational data. Numerous underground exposures show quartz crystals lining vugs (pl. 15) or extending out from vein walls (pls. 9, *A*, 17, and 18). The formation of dense milky quartz by the coalescence of "combs" is shown in plate 9, *A*. These observed facts permit only the interpretation that quartz filled open spaces. The sheared and brecciated vein material discussed on pages 41–42 resulted from movements of the vein walls, whereby new spaces were opened for the deposition of additional quartz (pl. 8, *C* and *D*). As the vein walls are not plane surfaces, movements that produced compression and crushing at one place would result in dilation elsewhere. That large vein areas will stand open with surprisingly little support is proved by the deep-level stopes in the mines today. Thus the thick quartz veins of the district can be readily conceived as resulting from repeated movement of the walls alternating with repeated deposition of quartz. This concept is diagrammatically illustrated in figure 43. In reality, of course, the pattern of reopened fractures is complex, and much wall rock is included in the veins.

SOURCE OF VEIN MATERIALS

An inquiry into the source of the vein minerals necessarily involves consideration of the source of the water which, presumably, transported them and from which they were deposited.

[43] Lindgren, Waldemar, op. cit., p. 172.

Bowen [44] estimates the actual amount of volatile matter, mainly water, in most igneous rocks at the time of crystallization to be less than 1 percent, a figure which Gilluly [44a] believes to be too low. Goranson [45] in his experiments on the solubility of water in melted granite found that granite glass obtained by melting granite from Stone Mountain at 900° C. under a pressure of 4 kilobars would dissolve 9.35 percent by weight of water. Basing his deduction upon further experimental work on the Stone Mountain granite, he says:[46]

> Let us assume we have a granite magma containing 1 percent of water in solution and at a depth of, say, 10 kilometers. It will begin to crystallize at about 1,025° C. Crystallization, with corresponding increase in concentration of water in the residual liquid, will proceed with continued cooling. When the temperature reaches 700° C. about 85 percent of the original magma will have crystallized, the residual liquid containing about 60.5 percent of water in solution.
>
> The residual solution, 15 percent of the original magma, would be available for the formation of aplites, pegmatites, and quartz veins; of this amount two-thirds would crystallize between 700° and 500°. Of the original magma containing 1 percent of water in solution we would have as final products 85 percent of granite (1,035° to 700°), 10 percent of aplite and pegmatite dikes (700° to 500°), and 5 percent of quartz veins (500° and lower).
>
> If this granite magma with 1 percent of water in solution lies at a depth of 4 kilometers crystallization will begin, as before, at about 1,025° and continue normally until the temperature drops to 950°, when about two-thirds of the original magma will have crystallized. At this point the pressure necessary to hold the increased concentration of water in solution will become equal to the hydrostatic head at this depth. But we know that the pressure-solubility curve is considerably steeper than the temperature-solubility curve at this pressure, hence further crystallization will be accompanied by an ebullition of water.
>
> There are these two coexistent fluid phases—one predominating in silicates and the other in water. Water will continue to boil out of the magma as silicates crystallize.

At a depth of 4 kilometers there would be little opportunity for the formation of aplites and pegmatites, and they would constitute, as they do at Grass Valley, only a small fraction of the total rock volume, whereas the phase predominant in water would probably be adequate in amount and in silica content to account for the quartz veins of the district. It should be remembered that the granodiorite at Grass Valley is but the cupola of an intrusive mass of unknown though great size, and it seems reasonable to suppose that a large fraction of the total volatile materials of the magma collected in the cupola.

In contrast to the foregoing outline of the magmatic hypothesis for the origin of the quartz in the Grass Valley veins, Knopf [47] says of the Mother Lode veins:

> The amount of quartz in the veins is only a fraction of the amount of silica liberated from the wall rocks by ankeritization. The wall rocks were a more than ample source for the quartz in the veins, hence it is unnecessary to appeal to a magma as the source of the silica.

At Grass Valley, too, the silica that has been removed from the wall rocks is more than would be required to fill the veins. At Grass Valley, however, the carbonates—ankerite and calcite—occur also in the veins, where they are later than the bulk of the quartz. As there is no positive evidence that there were two periods of carbonate deposition—an earlier one in which the wall rocks were ankeritized and a later one in which the vein ankerite was deposited—it seems more probable that carbonates were deposited in the wall rocks at the same time that they were deposited in the veins—after the period of quartz deposition. If that was the case, Knopf's explanation for the origin of the Mother Lode quartz is not generally applicable at Grass Valley, although it may account for the small amount of later vein quartz that is contemporaneous with the vein carbonates. This hypothesis meets with similar difficulty at Alleghany,[48] where the vein carbonates are younger than the vein quartz.

It appears most probable that the CO_2 that ankeritized the wall rocks, like the vein quartz, is of magmatic origin, for Shepherd [49] found that the CO^2 content of the volcanic gas given off by the Hawaiian volcano Kilauea ranged from 1.54 to 33.48 percent.

A magmatic origin is the only tenable explanation for the source of the metallic constituents of the veins—Fe, Pb, As, Sb, Cu, W, Ag, and Au. Pyrite and arsenopyrite were deposited with the earliest quartz, sphalerite and chalcopyrite were somewhat later, and galena and gold were introduced with the late quartz and early carbonates.

Because of the lack of gold in the wall rocks at Grass Valley, Knopf's comment on the distribution of gold in the Alleghany veins is equally applicable to Grass Valley. In reviewing Ferguson and Gannett's report, he says: [50]

> The close association of the gold with the main quartz filling of the veins, extremely close in spite of the fact that the gold was introduced much later than the deposition of the quartz, is indeed a remarkable enigma.

Possibly the relative abundance of gold in sheared quartz or broken pyrite and its scarcity in comb or massive quartz points toward the conclusion that the gold-depositing solutions, like those that brought in the quartz, were confined to permeable channels such as would be afforded by quartz that had been granulated by movement of the vein walls.

[44] Bowen, N. L., The evolution of the igneous rocks, p. 296, Princeton Univ. Press, 1928.

[44a] Gilluly, James, Water content of magmas: Am. Jour. Sci., vol. 33, pp. 430–441, 1937.

[45] Goranson, R. W., The solubility of water in granite magmas: Am. Jour. Sci., vol. 22, pp. 481–502, 1931.

[46] Goranson, R. W., Some notes on the melting of granite: Am. Jour. Sci., 5th ser., vol. 23, pp. 234–235, 1932.

[47] Knopf, Adolph, The Mother Lode system of California: U. S. Geol. Survey Prof. Paper 157, p. 45, 1929.

[48] Ferguson, H. G., and Gannett, R. W., op. cit. (Prof. Paper 172), p. 74.

[49] Shepherd, E. S., Composition of gases at Kilauea: Hawaiian Volcano Obs. Bull., vol. 7, no. 7, p. 95, 1919.

[50] Knopf, Adolph, Econ. Geology, vol. 28, p. 401, 1933.

MINES

PLAN OF TREATMENT

The mines of the district are briefly described in the following order: (1) Those on veins in the central and southern parts of the quadrangle, where granodiorite and diabase are the principal wall rocks, and (2) those on veins in the northern part of the quadrangle, where serpentine commonly forms one or both walls.

The principal geologic features of the mines that were accessible for study in 1930 and 1931 are shown on isometric block diagrams. Development maps showing the mine workings and stoped areas in the mines studied in detail represent conditions in 1931 except those of the Golden Center, Spring Hill, and Phoenix mines, which are complete to 1934. Most maps of mines studied are reproduced on a uniform scale of 1 inch to 400 feet. Working maps of mines that were not accessible in 1930 and 1931, so far as they could be procured, are reproduced on the same scale. They are likely to give somewhat more reliable information regarding the attitude, structure, and stopes than can be obtained from other sources. Brief descriptions of the inaccessible mines are based upon the published reports of Lindgren and MacBoyle, local informants, and mine maps.

The Golden Center, North Star, Empire, and Pennsylvania mines offered excellent opportunity to study the geology of the veins in the granodiorite area. The only new information about the veins of the serpentine area was obtained in a hurried visit to the Spring Hill mine in the summer of 1934.

VEINS ON THE WEST SIDE OF THE GRANODIORITE AREA

GOLD HILL, MASSACHUSETTS HILL, AND NEIGHBORING VEINS

The Gold Hill, Massachusetts Hill, and neighboring veins, which crop out south and west of the town of Grass Valley, strike north and dip both east and west. They were the first veins to be located in the district and were the principal producers in the early days of the camp. Most of the rich ore was extracted early, and by 1870 the mines had been closed. Later some of the mines were reopened and for a time operated with indifferent success. The Boundary mine, which was shut down in 1931, is the only one that was open at the time the present field work was done. The veins were generally narrow, and the valuable content, mainly in free gold, extremely irregular. Sulphides were relatively sparse and poor. The veins cropping out in diabase near the granodiorite contact passed into granodiorite in depth.

GOLD HILL MINE

Locally credited with being the site of the discovery of gold-bearing quartz in California, the Gold Hill mine, on the outskirts of Grass Valley, was worked from 1850 to 1867 and is reputed to have produced $4,000,000. In 1903 the mine was purchased by the North Star Co., which did considerable development work in search of new ore bodies. As no new ore was found, the mine was shut down and has since been idle.

Lindgren [51] gives the following description of the vein:

> The vein crops in diabase, but all of the lower workings are said to be in granodiorite. The strike of the vein, though very irregular, is north and south, and the dip is 28° E. The upper portion, near the croppings, is, however, in places much flatter, and the whole hill slope is completely honeycombed by drifts and shafts. The Gold Hill vein is very irregular in width, varying from a mere seam up to 6 feet, the average being said to be 2 feet. At 275 feet south of the shaft the vein is said to have been cut off by a fault fissure, striking northwest and containing no ore. The hanging wall of the Gold Hill is strongly impregnated with pyrite. The vein is characterized by irregular pay shoots, at places being almost entirely barren, while at other places large pockets of coarse gold occur. North of the Gold Hill shaft the vein is said to split, one branch extending north and the other northeast. It is impossible to verify this at present, the outcrops not being recognizable. The gold is from 850 to 870 fine.

MASSACHUSETTS HILL MINE

The Massachusetts Hill, or Rocky Bar, is probably a southerly continuation of the Gold Hill vein. It was discovered in 1850 and worked with few interruptions until 1866. During this period about $3,000,000 is said to have been produced. The Massachusetts Hill mine, which was worked through the Old Rocky Bar deep shaft, was acquired by the North Star in 1894 and produced $1,078,075 from 68,222 tons of ore, an average of $15.80 a ton, in the period from 1894 to 1901, when the mine was closed. Figure 44 shows the development work done in the Massachusetts Hill mine, and the position of workings in the adjoining Granite Hill and North Star mines.

CINCINNATI HILL MINE

The Cincinnati Hill vein, near the western boundary of the quadrangle, was first worked in the 1850's. In 1910 it was purchased by the North Star Co., and the old shaft was sunk to a depth of 400 feet. After drifting about 1,000 feet on a vein that yielded only 656 tons, carrying 0.27 ounce of gold to the ton, the mine was closed in 1912. Figure 45 shows the workings of this mine.

OTHER EASTWARD-DIPPING VEINS

The Shanghai vein, southwest of the Massachusetts Hill, and the Scotia vein, due west of Grass Valley, were worked by shallow shafts in the last century but have since been idle.

BOUNDARY MINE

The Boundary mine is just outside the west boundary of the town of Grass Valley, adjacent to the Peabody mine, with which it is connected on the third and deepest level. Three main veins are exposed underground; the Brock, the Peabody, and the footwall veins.

[51] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), pp. 233–234.

Fred M. Miller [52] has estimated the production of the Brock vein to be $182,000. Of this total, $12,000 came from early workings above 80 feet in depth, when the milled ore is said to have averaged 2 to 4 ounces to the ton. Recent workings to the third level have produced about $170,000 from ore averaging one-half to three-fourths ounce to the ton. Several high-grade pockets have yielded perhaps $25,000. The mine was closed in 1931.

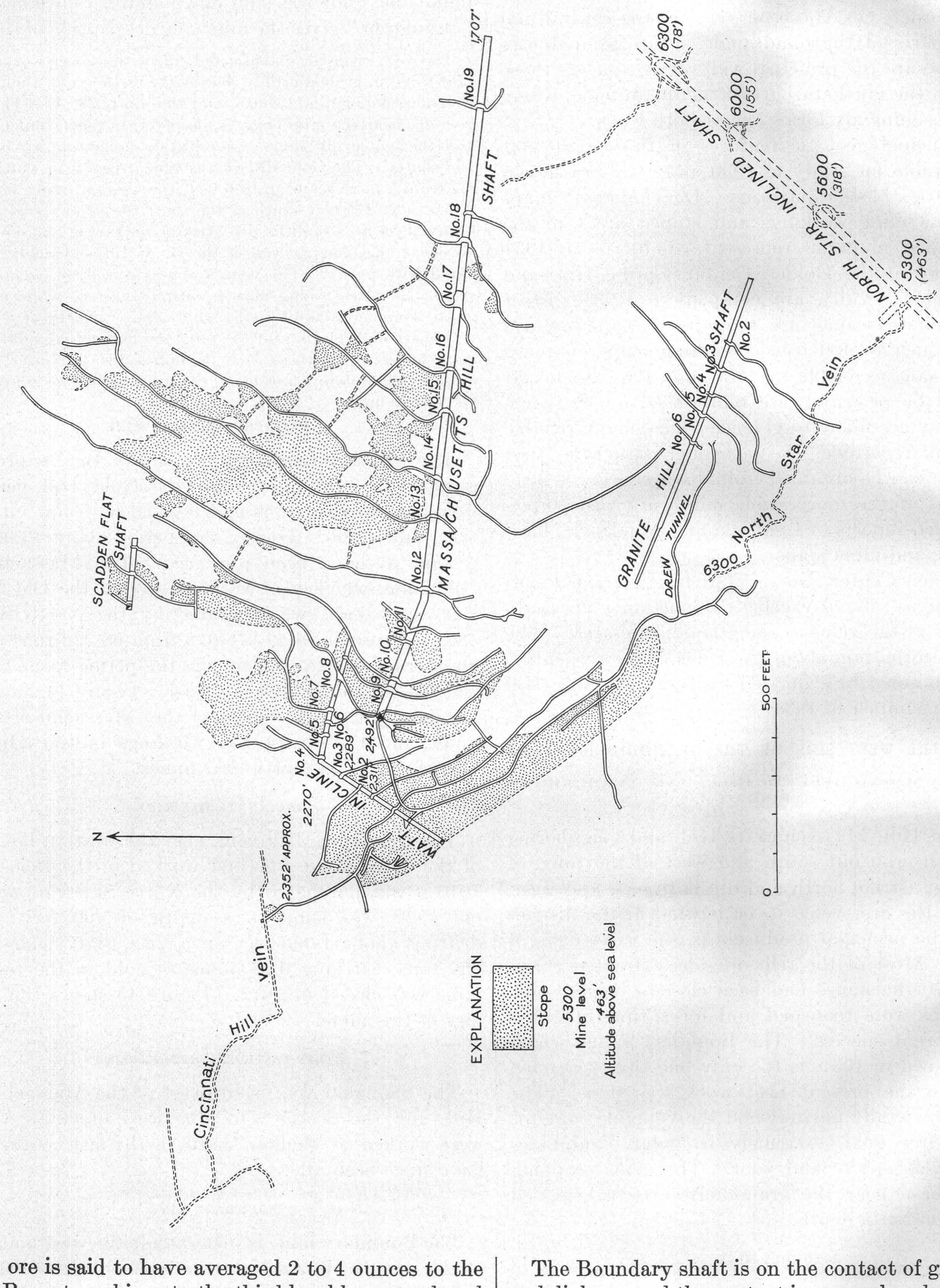


FIGURE 44.—Development map of the Massachusetts Hill and Granite Hill mines. Workings in the neighboring North Star and Cincinnati Hill mines are shown by dash lines.

The Boundary shaft is on the contact of granodiorite and diabase, and the contact is exposed underground on all the levels. The granodiorite contains several aplitic segregations without defined walls, in which the horn-

[52] Written communication, Oct. 29, 1934.

blende content is much less than is usual in the granodiorite. The diabase contains uralitic hornblende and is somewhat coarser than that exposed in the North Star mine. As is generally the case in the district, the diabase-granite contact is sharp, and hand specimens showing both rocks in typical facies are readily obtained.

galena, are sparsely distributed through the quartz. In the shaft just below the station on the second level a small vug of comb quartz contained well-crystallized pyrite. Coating the free surfaces of the pyrite crystals, and consequently younger than the pyrite, were clusters of epidote crystals. This is the youngest epidote observed in the district. Free gold was occasionally found. The stoped areas are shown on the development map (fig. 46). Further sinking on the Brock vein appears to offer the greatest likelihood of blocking out additional ore.

Footwall vein.—On the second level a crosscut into the footwall of the Brock vein intersected a second vein, called the Footwall vein, which is parallel to the Brock vein in strike but dips 35°–60° NE. This vein has been stoped for 100 feet along the strike, is also exposed on the second level, and the stope extends to the first level, where the vein curves westward and is cut off by the Brock vein. Mineralogically the Footwall vein is similar to the Brock vein.

A second northeastward-dipping vein, parallel to the Footwall vein, is exposed at the south end of the drift on the Brock vein on level 2 and has been stoped to a small extent.

Peabody vein.—On the third level a crosscut into the hanging wall of the Brock vein cuts the Peabody vein, which parallels the Brock vein in dip and strike. A short raise connects the third level with the 400-foot level of the Peabody mine. In the Boundary workings the Peabody vein is a narrow fracture filled with a few inches of quartz firmly attached to both walls. Malachite stains on the diabase of the drift walls indicate the relative abundance of chalcopyrite in the ore. According to local tradition, the old Peabody vein averaged 1½ to 2 feet in width and contained 2 percent of sulphides, as well as course gold.

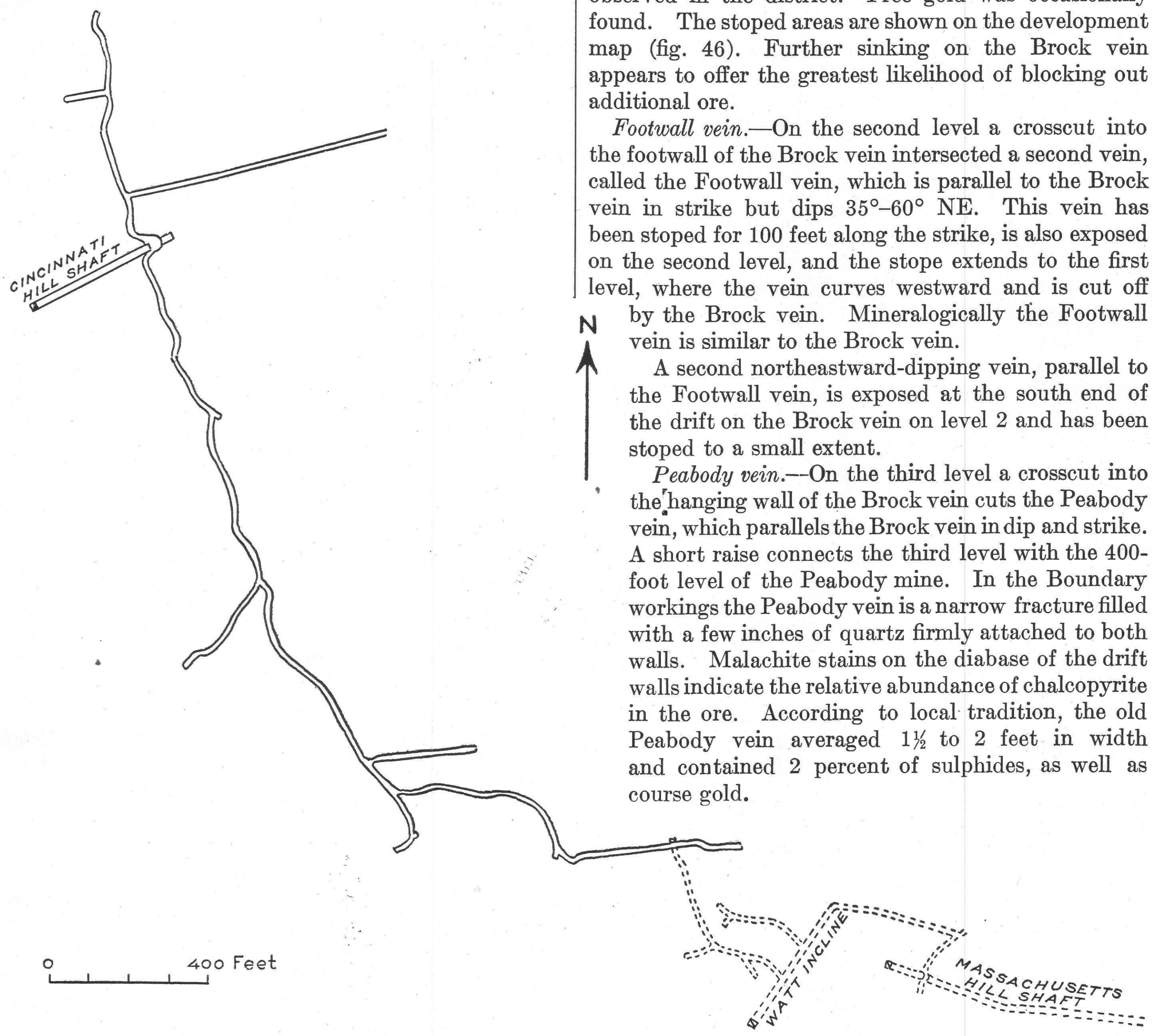


FIGURE 45.—Development map of the Cincinnati Hill mine. Workings in the neighboring Massachusetts Hill mine are shown by dash lines.

Brock vein.—The Brock vein strikes northwest and dips at an average angle of 50° SW. An inclined shaft follows the vein to the third level, at a depth of 230 feet below the surface. The vein has been followed on the first, second, and third levels. Generally strong walls are separated by quartz as much as 3 feet in thickness. There is less gouge than is usual for the district. Comb quartz and massive milky hypidiomorphic quartz are the common types. Sheared and brecciated quartz is less abundant. Sulphides, principally pyrite with some

The crosscut was continued to the west, and some drifting was done on a series of tight stringers lying in the hanging wall of the Peabody.

PEABODY MINE

The Peabody mine was worked in the early days of the camp and again from 1890 to 1893. Its workings, which adjoin those of the Boundary mine, are shown on figure 46. The Peabody vein is said to average 18 inches in width and to contain irregularly distributed coarse gold.

OTHER WESTWARD-DIPPING VEINS

The Hermosa vein strikes northeast and dips northwest at an average angle of 35°. In 1892 it was worked by a shaft 600 feet in depth but was closed soon thereafter. Hobson and Wiltsee [53] reported the vein to be 2 to 2½ feet in width and to be wholly diabase.

The Jersey Blue, southeast of Watt Park, strikes northeast and dips 20° NE.

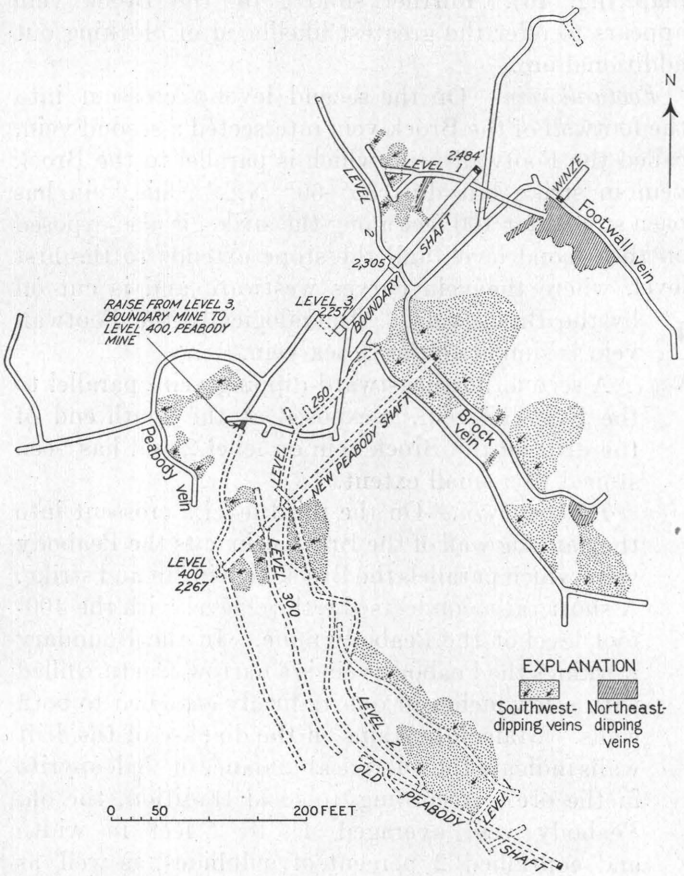


FIGURE 46.—Development map of the Boundary mine. Workings in the connecting Peabody mine are shown by dashed lines.

The Blue Ledge vein strikes north and dips 30° to 50° W. In the early days it is said to have produced $75,000. In 1892 the Hudson Bay shaft was sunk to intersect the vein. A stringer encountered at a vertical depth of 140 feet contained coarse gold enclosed in brown opal. The vein has not been worked in later years.

GOLDEN CENTER MINE

HISTORY AND PRODUCTION

The Golden Center mine, whose head frame is within the town limits of Grass Valley, just south of Wolf Creek, is a consolidation of the Rock Roche, Dromedary, and Berriman properties.

The mine was first worked in the early 1850's, again in 1863, and from 1868 to 1874, when the ore is reported to have ranged in value between $10 and $60 a ton. In 1912 the property was acquired by the Golden Center of Grass Valley Mining Co., which sunk the present shaft to the 1,100-foot level and crosscut on the 500-foot level to the Garage, Sleep, and Church Hill veins. In 1931 the mine was acquired by Cooley Butler, of Los Angeles, and between 1931 and 1934, under the management of Leland Wincapaw and Wallace Butler, the shaft was deepened to the 1,300-foot level, and the 1,100-foot crosscut to the Garage and Church Hill veins was driven.

F. M. Miller,[54] a mining engineer long resident in Grass Valley, has estimated the total value of the mine's production between the 400-foot and 1,300-foot levels as $2,250,000.

THE VEINS

The principal veins exposed in the Golden Center mine are the Dromedary, Garage, Church Hill, and Sleep. All strike north or northeast and dip west or northwest and all are contained wholly within the granodiorite. Outcrops are obscure, as they lie within the town limits and have been largely covered by grading, building, and paving.

On Lindgren's map the Wyoming, Crandall, and Granite Hill mines, all south of the Dromedary, are assumed to be on the same vein and are connected by dotted lines. There has been no mining on the southern part of the vein in recent years. The mine workings of the Granite Hill are shown in figure 44.

Most of the quartz of the various veins is massive and milky. "Combs" and sheared and brecciated textures are common, however. Chalcedony filling the interstices in "combs" and cementing quartz breccias was observed in several places. Likewise both calcite and ankerite are later than the quartz. Pyrite, galena, sphalerite, and chalcopyrite are the principal sulphides.

Dromedary vein.—The Dromedary vein, upon which most of the development work of the Golden Center mine has been done, has an average strike of N. 30° E. and an average dip of 38° NW. As shown on the development map (pl. 25), the strike of the vein in the section of the shaft is approximately north-south. A short distance north of the shaft the strike swings to the northeast where the vein is intersected by a series of strong crossings. There the angular divergence in strike between the vein and crossings ranges between 0° and 30°. The vein, with an average dip of 38°, is repeatedly offset on the crossings, which dip 70° to 90°, forming a series of steps as shown in figure 26 and in the cross section in figure 47. Locally the crossing walls, where exposed in drifts paralleling them, are called "breast heads." Quartz follows the crossing

[53] Hobson, J. B., and Wiltsee, E. A., State Mineralogist 11th Rept., pp. 280-281, California State Mining Bureau, 1893.

[54] Miller, F. M., Map of lode and placer mining claims and groups of mining properties of the western portion of Nevada County, Calif. (blueprint published by the author), Grass Valley, 1934.

from one segment of the vein to the other, but usually does not continue beyond. Although the offset of the vein on the crossings is mainly premineral, postmineral movement on both veins and crossings has occurred in places. This steplike arrangement of vein material on vein and crossing fractures is possible only on veins striking to the northeast, roughly parallel with the strike of the crossings. It is not, however, characteristic of all northeastward-striking veins or of all veins of the Golden Center mine, for the Church Hill and Garage veins appear to hold the same dip between the 500- and 1,100-foot levels.

The Dromedary vein was readily followed in the shaft to the 1,100-foot level, and stoping established the continuity of the vein on the north side of the shaft. Below the 1,100-foot level the shaft cut a strong crossing, along which much water circulated and upon which the vein abruptly steepened. Beyond the crossing at the 1,300-foot station the vein was not found, although it has not been looked for in the foot-wall. Similarly the vein steepened at the winze from the 1,100- to the 1,300-foot level, north of the shaft.

Garage vein.—The Garage vein, which strikes northeast and dips 38° NW., roughly paralleling the Dromedary vein and lying in its hanging wall, was first encountered on the 500-foot level crosscut. Later it was found in the 700- and 1,100-foot levels, as shown in the section (fig. 47). Some stoping has been done on the 500- and 1,100-foot levels, and an inclined winze was sunk from the 1,100-foot level to a sublevel 26 feet vertically below.

The Garage vein is less broken than the Dromedary vein. Both main walls are usually exposed in the drifts. The quartz ranges from 2 or 3 to 20 inches in thickness. Usually it is frozen to one wall; commonly to both walls. In places it fills a splintered fracture several feet wide, forming a sheeted zone of narrow quartz seams.

Church Hill vein.—Like the Garage vein, which it parallels, the Church Hill vein was first met on the 500-foot crosscut near its junction with a footwall split called the Sleep vein. A short distance east of the discovery point an ore shoot was encountered. A winze was sunk at the junction of the Church Hill and Sleep veins, and a sublevel driven through ore. On the sublevel the shoot was about 135 feet long and averaged 14 inches of quartz that contained a little over 2 ounces of gold to the ton. A mill test of 79 tons of quartz from a slope above the 500 level showed an average gold content of about 0.75 ounce to the ton. In 1933 the 1,100-foot crosscut reached the Church Hill vein, and drifts were driven in both directions. Some good ore was found, and in the summer of 1934 stoping was in progress.

Structurally the Church Hill vein more closely resembles the Garage vein than the Dromedary vein, for the vein walls are close together and the quartz is commonly frozen to them. Ribbon structure and quartz breccias were observed on both the 500-foot and the 1,100-foot levels.

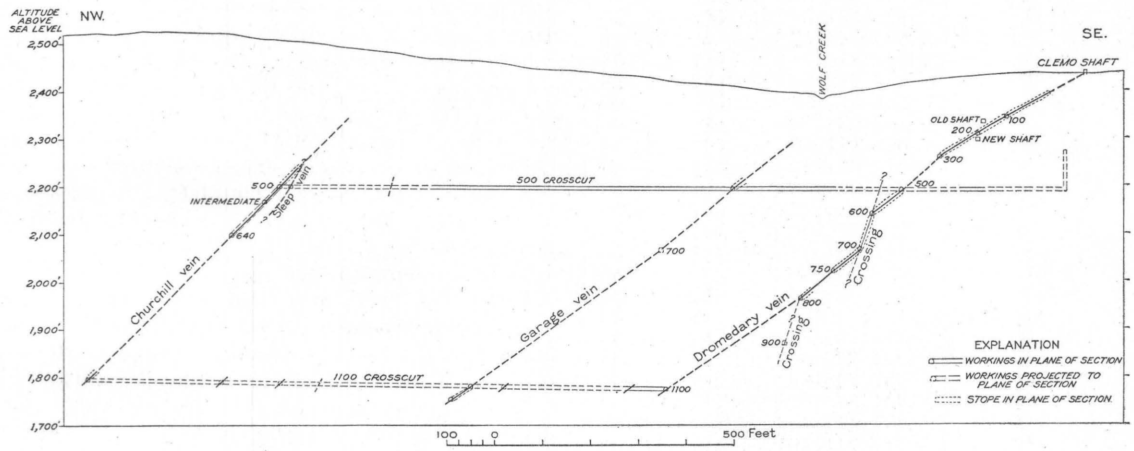


FIGURE 47.—Vertical section striking N. 40° W. through the 500-foot level crosscut of the Golden Center mine.

Sleep vein.—The Sleep vein is a footwall split of the Church Hill vein diverging to the southwest at an angle of 20°. Some stoping was done on the 500-foot level, but the Sleep vein was not recognized on the 1,100-foot level. (See cross section, fig. 47.)

NORTH STAR MINE

HISTORY AND PRODUCTION

The North Star mine is one of the three largest producers of the Grass Valley district. From the beginning of mining in 1851 through 1928, the last year of operation by the North Star Mines Co., it had produced over $29,000,000. The ore averaged 0.514 ounce a ton for the span of years from 1884 to 1928. On May 1, 1929, the Newmont Mining Corporation purchased controlling interest in the North Star mine and now operates it in conjunction with the Empire as the Empire-Star Mines Co., Ltd.

Production of the North Star mine, 1884–1928 [1]

Year	Ore crushed (tons)	Production	Yield per ton (gold at $20.67 an ounce)	Gold per ton (ounces) [2]
1884–1886	9,826	$196,824.34	$20.031	0.97
1887	14,821	287,939.38	19.427	.94
1888	17,269	334,120.85	19.348	.93
1889	17,902	312,128.83	17.435	.84
1890	12,538	196,270.63	15.654	.75
1891	14,978	266,088.86	17.764	.85
1892	13,231	235,391.06	17.790	.86
1893	10,637	332,925.19	31.297	1.51
1894	7,446	133,233.90	17.892	.86
1895	7,623	106,122.73	13.921	.67
1896	13,145	118,868.73	9.043	.43
1897	15,912	319,234.41	20.061	.97
1898	21,736	397,098.44	18.269	.88
1899	25,763	321,998.47	12.498	.60
1900	13,750	150,160.50	10.920	.52
1901	13,203	138,382.94	10.481	.50
1902	17,399	411,147.98	23.630	1.14
1903	28,790	736,087.31	25.567	1.26
1904	49,586	781,237.34	15.755	.76
1905	77,530	876,361.31	11.303	.54
1906	84,672	826,326.57	9.759	.47
1907	78,366	937,816.78	11.967	.58
1908	90,107	1,084,212.08	12.032	.58
1909	91,610	1,245,077.83	13.591	.65
1910	90,110	1,232,933.96	13.683	.66
1911	95,401	1,025,087.52	10.745	.52
1912	101,837	1,042,024.52	10.232	.49
1913	106,090	1,200,096.42	11.312	.54
1914	107,250	1,115,586.97	10.402	.50
1915	109,860	1,089,750.75	9.919	.48
1916	111,330	1,160,007.44	10.419	.50
1917	100,500	1,148,684.89	11.430	.55
1918	99,550	775,688.18	7.792	.37
1919	102,800	919,799.93	8.947	.43
1920	61,400	718,286.33	11,698	.56
1921	76,000	922,769.58	12.142	.58
1922	115,600	1,087,705.99	9.409	.45
1923	89,500	741,336.67	8,283	.40
1924	109,200	871,472.41	7.981	.38
1925	94,600	774,941.10	8.192	.39
1926	94,600	743,048.00	7.71	.37
1927	108,706	881,320.00	8.10	.39
1928	108,600	836,568.00	7.70	.37
	2,630,780	29,032,155.00	11.035	.53
1851–1857 [3]		250,000.00		
1860–1874 [3]		2,500,000.00		
Estimated total production		31,782,155.00		

[1] Production for the period 1884–1925 from the annual report of the North Star Mines Co., 1925; for the period 1926–1928 from A. B. Foote.
[2] Approximate figure derived by dividing yield per ton in dollars by 20.67. No allowance for silver has been made.
[3] Estimated by Lindgren, op. cit. (17th Ann. Rept.), p. 238.

William Hague and W. D. Pagan [55] give the following history of the North Star from 1851 to 1914:

The discovery of what is now known as the North Star vein was made by two Frenchmen, the Lavance brothers, while sluicing on the side of the hill where the North Star mill now stands, probably in the fall of 1851, for on November 10 they recorded the first location. The vein was first known as the French lead, and the hill on which it outcropped was called Lafayette Hill. In the next few days nine other Frenchmen recorded their locations, each claim being 100 feet square. These Frenchmen evidently decided to form a combination in restraint of "jumping," as the Helvetia & Lafayette Gold Mining Co. was formed by some of them in the course of a year or two to work their claims. The discovery attracted many prospectors, and the records show several hundred locations made in the next few months, many of which were "jumped" at various times. Just east of Lafayette Hill some of the later owners located the eastern extension of the North Star vein, upon what they called Weimer Hill. Whether or not this Teutonic name was chosen to irritate the Frenchmen on Lafayette Hill does not appear. The locations forming the Helvetia & Lafayette property took 480 feet along the strike of the vein and appear to have been about where the present North Star shaft house stands. East of the Helvetia & Lafayette for 800 feet came another consolidated group of claims known as the Independence, and for 800 feet east of this came the White Rock group. A group of claims known as the North Star was located some time prior to 1860 on a split from the vein in the hanging wall over the Helvetia & Lafayette ground.

[55] Min. and Sci. Press, Oct. 10, 1914, pp. 549–552.

In 1858 the Helvetia & Lafayette came to grief and was sold by the sheriff to Edward McLaughlin to satisfy judgments for $8,000. In February 1860 McLaughlin sold the property to J. C. Pascoe, Edward Coreman, and others for $15,000. These men also owned the North Star group, and in 1861 they formed a mining partnership known as the North Star Quartz Mining Co. Between 1861 and 1866 many of the other claims in the neighborhood were bought by this company. Bean's Directory states that the net profits for the 5 years ending 1866 were $500,000, or at the rate of $100,000 per annum. The tonnage milled was probably about 7,000, and the total outlay about $150,000 per annum. This would mean that the mine produced, say, 35,000 tons, with a gross yield of $1,250,000 during this period—probably too high an estimate. The gross production, therefore, for the 5 years is assumed at $1,000,000. It is also estimated that for the 10 years previous to 1861 the vein produced 25,000 tons, yielding $500,000, making a total from 1851 to 1866 of $1,500,000 from ore averaging $25 per ton.

In 1867 the North Star Gold Mining Co. was incorporated, with a capitalization of $1,000,000. This new company purchased from the North Star copartnership the Helvetia & Lafayette, the North Star, the Independence, and other claims on the Weimer and Lafayette Hills. These various claims were consolidated as the North Star claim, under United States patent issued on August 11, 1875.

In 1875 the mine was closed down, being then about 1,200 feet deep on the incline, a decrease in the yield of the lode making its operation unprofitable. From a report by Joshua E. Clayton made in 1869, and from figures given in the "Mineral resources west of the Rocky Mountains" for the years 1871, 1872, 1873, and 1874, it is estimated that the mine produced between July 1867 and September 1873 some 50,000 tons, yielding $1,125,000 in round numbers. The expenses were in the neighborhood of $150,000 per annum, which would indicate a profit of $225,000.

In May 1884 the North Star Mining Co. was incorporated, with a capitalization of $1,000,000, to take over the property of the North Star Gold Mining Co., and the mine was reopened and the shaft sunk. Since that date the vein has produced continuously, though for several years prior to 1902 in a very limited way.

Between 1884 and 1894 the North Star shaft was sunk to the 2,300-foot level, and the ore shoot that had been followed from the surface and which lay for the most part west of the shaft was stoped. Very rich rock was found on the 1,800-foot level near a displacement in the vein caused by a "crossing." Good ore was also extracted between 1,900 and 2,100 feet, which made the yield in 1893 over $31 per ton. This ore shoot produced in round numbers 250,000 tons yielding $5,250,000. At the 2,300-foot level, however, the quartz ceased, and the vein below it became small and "tight."

Although the outlook at the time was not particularly encouraging, it was decided to sink a vertical shaft to intersect the vein at a depth of 4,000 feet on the dip, and work was commenced in

1897. To provide funds for the purchase of additional claims and more extensive explorations, the capital of the North Star Mining Co. was increased in 1894 from $1,000,000 to $2,000,000; and in April 1899 the North Star Mines Co. was incorporated under the laws of New Jersey, with an issued capital of $2,500,000 to take over the property of the North Star Mining Co. and to furnish the funds required for the expensive undertaking of sinking the new shaft.

Exploration to the eastward had hitherto disclosed a barren vein and had never been pushed far. In 1900, after certain adjoining claims had been purchased, the 500-foot level was extended eastward and after being driven some distance passed through the top of a narrow shoot of rich ore. Surface indications overhead had never encouraged prospecting in this direction before. Exploration was hastened on the 1,100 and 1,900 east, because of this discovery, and the downward extension of the shoot was discovered. The ore from this was rich, from one place 18,000 tons yielding an average of $37.50 per ton. Operations in this ore body and in one a few hundred feet east of it, between and including the 1,100- and 2,700-foot levels, continued until 1911 and resulted in a total production of about 182,000 tons.

On March 31, 1901, the vertical shaft begun in 1897 cut the North Star vein at a vertical depth of 1,630 feet, or a depth of about 4,000 feet on the dip of the vein. Development work was for some time hindered by the heavy flow of water and by the necessary equipment of the shaft for more extensive operations. Levels were, however, started east and west, and a rise was begun to connect with the bottom of the incline shaft. The rise was carried upon the vein and finally connected with the incline shaft on November 22, 1903.

Subsequent developments have proved that the vein in the deep levels is wider and more extensive than in the upper mine, although the yield per ton is lower. The most productive level has been the 3,700, which will probably, first and last, yield over 200,000 tons, or four-fifths as much as the ore shoot that the mine was opened on. This level also has the distinction of having furnished a pocket of high-grade ore, worth $40,000, which was brought to the surface in some 20 candle boxes.

Since March 1901 to the end of 1912, successful development and profitable operation of the ground worked through the vertical shaft have continued, with levels extended to various lengths, east and west from the shaft, at 3,000, 3,400, 3,700, 3,900, 4,000, 4,700, 5,000, and 5,300 feet. In 1906 the shaft, following the vein on the incline, was continued below the 4,000-foot level and had reached a depth of 5,390 feet, when work was temporarily suspended in June 1908. The development work in the lower mine amounted, in all, to the end of 1912, to 43,192 feet.

In 1914 development work on the 6,300-foot level disclosed a new vein, called the X or No. 1, dipping southwest, conjugate to the North Star vein. As the North Star vein had been unproductive below the 5,300-foot level and could not be followed beyond this intersection, development was begun on the new vein. Meanwhile a second new vein, called the No. 2, which branched from the X vein 1,200 feet east of the North Star station on the 6,000-foot level, had been found. An inclined winze was sunk from the 6,300-foot level on the No. 1 vein and had reached the 6,600-foot level in 1924, when a wholly new development plan was decided upon.[56] This plan involved four projects—(1) to sink the vertical Central shaft, which bottomed at the 4,000-foot level, approximately 2,000 feet to intersect the No. 1 vein at the 8,600-foot level; (2) to continue sinking on the X vein, until it was vertically under the Central shaft; (3) to sink an inclined winze on the No. 2 vein, following a promising ore shoot, to the 8,600-foot level; (4) and to connect the vertical shaft with the bottoms of winzes 1 and 2 by drifts on the 8,600-foot level. This development plan was completed in November 1927, at a cost of $882,081. During the two years the development program was under way 242,900 tons of ore producing $1,518,000 and yielding a profit of $173,550.00 was mined, making the net deficit for the development $708,531.00.[57]

In 1928 a winze was sunk from the 8,600-foot level on a third new vein, called the No. 3, which lies in the footwall of the X vein and dips parallel to it. This winze bottoms on the 9,000-foot level, at a vertical depth of 3,700 feet beneath the surface of the ground. Drifts on the 8,700- and 9,000-foot levels have cut some ore. The best was in a small rich ore shoot near the winze that bottomed on the 8,700-foot level, but in 1929, of a total drift length on this vein of 3,600 feet, only 22 percent has been in stoping ground.

Other veins mined through the North Star shafts under the ownership of the North Star Mines Co. are the A or Alioth, New York Hill, Y, and Z veins, which are described below. The space relations of these veins are shown in figure 48.

In 1930, under the new ownership of the Empire-Star Mines Co., a winze was sunk on an ore shoot on the No. 2 vein from the 8,600-foot to the 8,700-foot level. Drifting on the 8,700-foot level had disclosed some good ore.

The general policy of the Empire-Star Mines Co., since the acquisition of the North Star mine, has been to develop the veins laterally rather than to deepen the mine, owing primarily to the high cost of deep exploration which necessitates frequent rehandling of ore and mine waste.

The following table shows the total amount of drifting on the different veins and the percentage of drift length that had been stoped by 1930. The percentage stoped on the North Star vein is somewhat high in comparison with that on the other veins, because the total figure includes the old shallow drifts where the levels in the discovery ore shoot were spaced 100 feet apart rather than at 300-foot intervals, as they were below the 2,300-foot level. The table shows that the North Star, New York Hill, A, Y, and No. 2 veins, all of which were mined with profit, were stoped for distances that averaged more than 30 percent of the total length of drift, whereas the X, No. 3, and "Connecting" veins, which did not pay development costs, have less than 30 percent of their drift lengths through stopable ground.

[56] Foote, A. B., Vertical and incline shaft sinking at North Star mine: Am. Inst. Min. Met. Eng. Tech. Pub. 324, p. 3, 1930.

[57] Idem, p. 18.

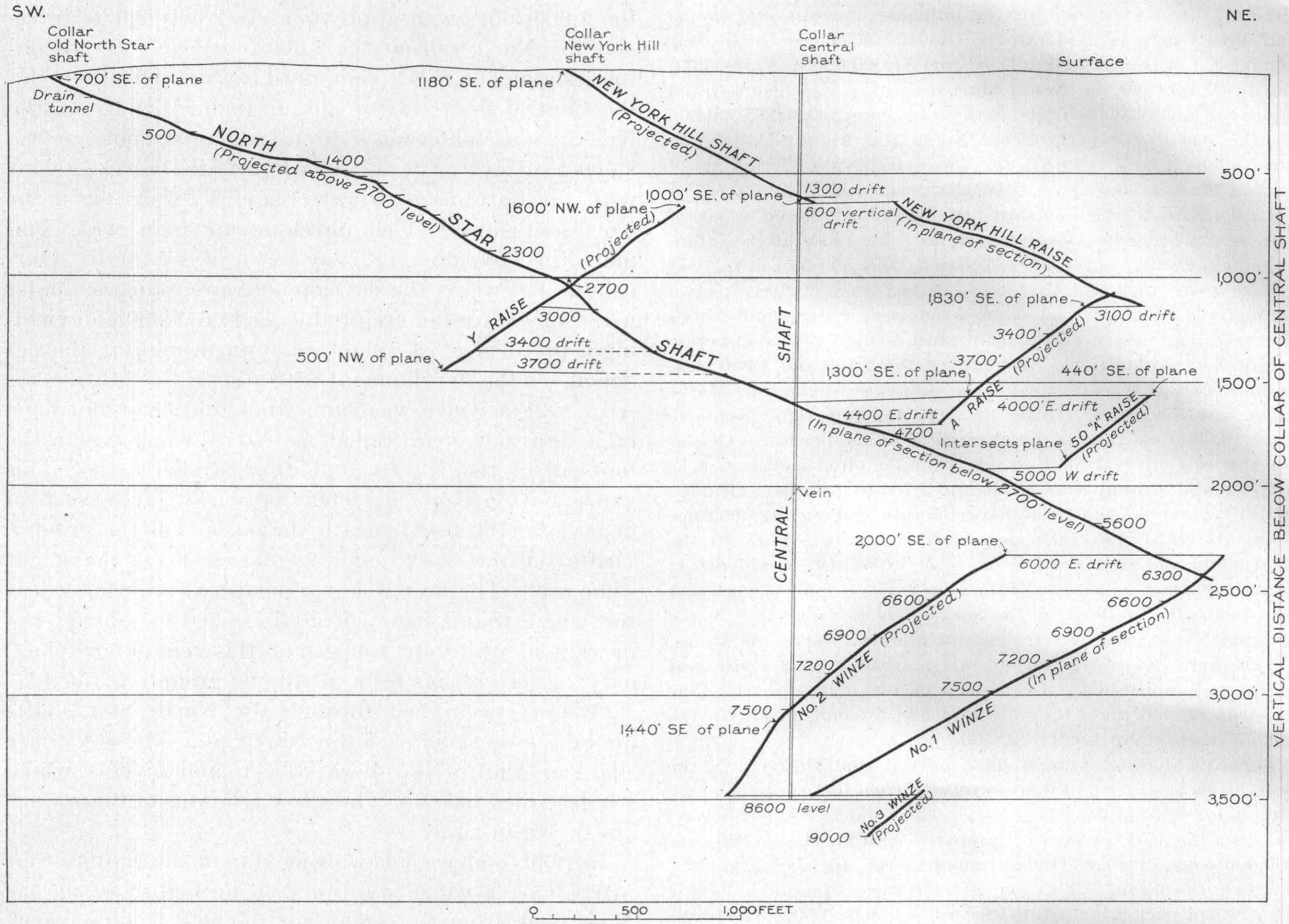


FIGURE 48.—Diagrammatic section through the North Star shaft with projection of principal raises and shafts on other veins. Plane of projection strikes N. 44° E. Connecting drifts are shown in light lines. Based upon 1926 section by A. B. Foote.

Length of drifts and percentage of drift lengths that had been stoped, North Star mine, 1930

Vein	Levels	Length of drift (feet)	Percentage stoped
North Star vein	100 to 1,000	11, 700	80. 34
	1,100 to 2,000	28, 700	31. 35
	2,100 to 3,000	12, 000	41. 66
	3,400 to 4,000	15, 400	42. 85
	4,400 to 5,000	10, 900	32. 11
	5,300 to 6,000	7, 300	20. 52
	All levels	86, 000	40. 69
New York Hill vein	New York Hill and Chevane shafts.	11, 200	51. 78
	600 North Star	3, 900	15. 38
	Below 600	4, 800	0. 00
	All levels	19, 900	32. 16
A vein	do	11, 200	36. 60
Y vein	do	6, 200	35. 48
X vein	do	16, 300	22. 69
No. 2 vein	do	11, 400	33. 33
No. 3 vein	do	3, 600	22. 22
"Connecting" vein	do	2, 100	0. 00
All veins		[1] 156, 700	36. 02

[1] Equals 27⅓ miles.

NORTH STAR VEIN

Attitude and dimensions.—The North Star vein has been followed down the dip for 6,300 feet and along the strike for 2,600 feet. It strikes northwest and dips northeast, but there are many irregularities in both strike and dip, as are shown in the profile of the North Star shaft (fig. 48) and the stope map of the vein (pl. 26). The dip of the vein ranges from 11° to 38° and averages 26°. (See pl. 28.)

Little now remains to be seen of the vein croppings, for all the prospect pits which exposed them in the early years are covered. Lindgren traced the ledge for a quarter of a mile east of the collar of the old North Star shaft near its junction with the Central North Star vein. To the west the croppings could not be followed into the Calaveras formation.

Wall rocks.—The contact between the diabase complex and the granodiorite is cut near the 4,000-foot level by both the vertical and inclined shafts, and drifts on that level follow the contact approximately. A few apophyses of granodiorite extend above this level, and one of them is cut by the 3,700-foot level at its junction with the drift to the Y vein. The position of the contact is shown on the isometric projection of the vein (pl. 27).

The contact between the unaltered granodiorite and the diabase complex is unusually sharp and shows no evidence of assimilation by the granodiorite. Close to the vein, however, where both rocks have been extensively replaced by sericite and carbonates, the similarity of the replacement products makes the identification of the contact more difficult.

Three granodiorite dikes in the diabase complex, ranging between 30 and 50 feet in thickness, are cut by the west drifts on the 3,700-foot level, and a narrow dike is cut by the west drifts on the 2,700-foot level. The granodiorite dikes, like the main mass, have sharp walls.

be seen in the bed of Wolf Creek north of the Omaha mine. These smaller dikes and the larger dike near the Omaha mine appear to coincide with those cut by the east drift of the North Star vein. As most of the dikes exposed pinch and swell and some of them do not extend for any great distance on their strike, there is no justification for assuming that those exposed in the North Star mine workings are continuous to the surface.

In addition to the aplitic dikes found in the upper part of the North Star workings there are several basic dikes, mainly diabase and porphyrite, that cut the granodiorite at approximately right angles to the strike of the vein. These dikes are in general narrower than the aplitic dikes. They, too, have sharp contacts. One of the basic dikes of particular interest appears to

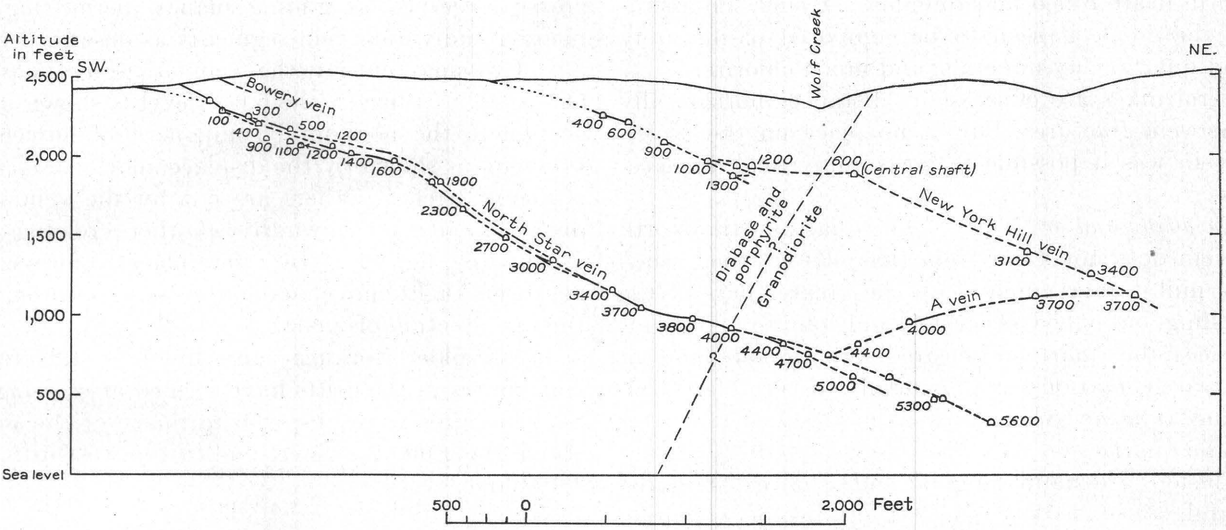


FIGURE 49.—Section parallel to No. 1 shaft, 230 feet southeast of collar of North Star inclined shaft.

Average value of ores at different depths, North Star mine [1]

Dates	Depth on dip (feet)	Ore milled (tons)	Average value per ton
1852–1866	750	[2] 60, 000	$25. 00
1867–1875	1, 200	50, 000	22. 50
1884–1913 [3]	1, 200–2, 700	328, 000	16. 44
1901–1913 [4]	3, 000–4, 400	732, 000	11. 87
1914–1918 [4]	3, 000–4, 400	428, 940	10. 52
1918–1928	4, 400–8, 700	1, 060, 501	8. 74

[1] Logan, C. A., Nevada County: California State Mineralogist Rept., vol. 26, no. 2, p. 122, April 1930.
[2] Estimated total.
[3] So-called upper mine workings. Mine idle from 1875 to 1884.
[4] So-called lower mine workings.

The east drifts of the North Star vein above the 4,000-foot level cuts a group of nearly parallel quartz porphyry dikes of varying widths. The dike that is most continuously exposed is cut on the 4,000-, 4,700-, 3 400-, 3,000-, 2,700-, 2 300-, and 1,900-foot levels. Smaller quartz porphyry dikes west of the shaft are intersected by the 3,700-, 2,700-, 2,300-, 1,900-, and 1,800-foot level drifts. The walls of these dikes are relatively sharp and show only slight transitional zones. Lindgren mapped a large quartz porphyry dike near the Omaha shaft. Smaller quartz porphyry dikes can

be an eclogite containing about 15 percent of garnet. This was cut by the extreme western face of the 3,700-foot level, and its attitude could not be determined.

Detailed petrographic descriptions of these rocks can be found on pages 7–18.

Vein fracture.—The North Star vein is not a simple fracture but rather a fracture zone whose main walls dip between 11° and 38° and whose width between walls ranges from a few inches to more than 20 feet. Between the main walls the country rock is broken and replaced by carbonates and sericite. Minor fracture planes with varying dips strike into both the hanging wall and the footwall at close intervals, usually at a low angle with the main walls. The quartz vein filling commonly follows either the hanging wall or the footwall and in places both. Smaller stringers of quartz extend from one wall to the other and less commonly quartz stringers follow minor walls a short distance into the country rock away from the vein.

In places the walls come together, and the vein is represented by a narrow fracture occupied by a thin seam of gouge. These pinches are, however, accompanied by an increase in the number of diverging minor walls extending out into the country rock.

In many places on the vein the walls are marked by large vertical grooves and ridges, with a relief of as much as 5 feet and a distance from crest to crest of as much as 30 feet.

In other places each of the two main walls is marked by a thin gouge seam, and they are separated by broken masses of country rock that form "horses" between well-marked walls. In such places the rock between the walls has undergone more complete replacement by carbonate and sericite than the country rock lying without the main walls.

Although gouge is usually confined to narrow seams on either wall, in places it occupies the entire width of the vein fracture, and fragments of wall rock contained in it are rolled and rounded. Under the microscope the gouge is seen to be composed of minutely ground quartz, clay minerals, and much chlorite.

Several dikes are offset short distances horizontally by the vein fractures, but at no place on the North Star vein was it possible to measure vertical displacements.

Vein filling and ore shoots.—The quartz in the North Star vein does not differ from that of the other veins. Dense milky quartz makes up the greater part of the vein filling, but euhedral crystals and combs are present. In places the quartz is sheared and broken, and at least two generations are commonly discernible. Calcite and ankerite, where present in the vein, are later than the quartz.

Inclusions are mainly angular and usually distributed uniformly through the vein. An interesting exception is shown, however, on the 2,700-foot level east (pl. 8, *A*), where the inclusions fill depressions in the footwall and suggest that the wall-rock fragments fell into a partly filled fissure and were in part supported by early quartz crystals on the footwall.

Pyrite, chalcopyrite, sphalerite, and galena are the sulphide minerals present. The sulphides are usually broken, and gold occurs along fractures in them as well as in the sheared and granulated quartz. Gold from the North Star vein averages between 0.850 and 0.870 fine.

The average value of ore mined from all veins in the North Star mine up to 1929 was $11.035 a ton, and the average for the North Star vein was somewhat higher. The highest yearly average reported during the period 1884–1928, for which complete records are obtainable, is for 1893, when the yield per ton was $31.297, and the lowest yearly average, when all ore came from the North Star vein, was $9.043 in 1896. These figures refer to gold at $20.67+ an ounce.

The shape and extent of the ore shoots are shown on plate 26. About 41 percent of the total length of the drifts on the North Star vein is stoped ground. The range is from 80 percent for the vein above the 1,000-foot level to 20 percent for the vein below the 5,300-foot level. A detailed table showing percentage of drift length stoped is given on page 70.

Crossings.—In addition to the vein fractures, which dip at relatively low angles, there are hundreds of "crossings," all striking in the northeast quadrant. Some crossings are simple fractures; others are fracture zones as much as 20 feet or more wide. Usually the simple crossings contain some gouge, and adjacent to the vein many contain quartz. The quartz is, however, usually confined to the vicinity of the vein and pinches out a few feet away from it. In many places the crossing walls are altered by the introduction of carbonates and sericite and, in diabase particularly, by pyrite.

The earliest crossings served as channels for the intrusion of both basic and acidic dikes, and later crossings served as gliding planes, permitting movement of individual vein segments as described on page 33. Crossings cut by the vein are sometimes offset. One such crossing on the 5,600 level is shown in figure 41, where the horizontal component of movement of the vein, as shown by the displacement of the crossing, is about 2 feet. Others are cut by the vein without displacement, as shown by another crossing on the same level (fig. 42). In a few places, however, there has been slight movement on crossings subsequent to the introduction of quartz.

In the older workings large limonite stalactites and stalagmites in the drifts have formed at crossing zones. Such features were observed in many of the workings above the 4,000-foot level and in the west drift on the 4,400-foot level.

A VEIN

Attitude and dimensions.—The A or Alioth vein strikes north-south and dips west at an average angle of 25°. It is a blind vein which was first encountered by the east drift on the 4,000-foot level of the North Star vein, approximately 1,800 feet east of the central shaft. It has been followed north and south along the strike for a distance of 3,000 feet and up the dip above the 4,000-foot level for 1,200 feet to the 2,700-foot level, where it was lost in the footwall of the New York Hill vein. Below the 4,000-foot level the A vein was cut by the east drifts on the North Star vein on the 4,000- and 4,700-foot levels, and by the west drift on the North Star vein on the 5,000-foot level. A raise, near the north end of the vein, connects the 5,000-foot with the 4,000-foot level and establishes the continuity of the vein. Thus the gross dimensions of the vein, as established by all drift intersections, are about 3,000 feet on the strike and 2,000 feet on the dip. These relations are shown on the stope map (pl. 29).

The A vein is cut off on the north by the New York Hill vein and has not been found beyond it. Near the junction the A vein flattens and numerous splits turn into the footwall of the other vein. The strike of the vein junction is N. 20° W. and the dip is 10° W.

The vein lies mainly in granodiorite. Roof pendants of diabase are cut at the south end of the 3,400- and 4,000-foot levels.

Vein fracture and ore shoots.—There is considerable variation in the character of the vein fracture. In places a simple fracture with little gouge contains quartz as much as 3 feet in thickness; elsewhere the vein is much broken and forms a stockwork of interlacing fractures as much as 12 feet from wall to wall. On the north end of the 4,000-foot level the vein is particularly broken and many poorly defined quartz stringers branch out into the hanging wall.

Although sheared vein material is abundant, in general the quartz is less broken by postquartz vein movement than the quartz of the North Star vein. Vugs and carbonate-filled quartz combs were seen on all levels. Usually the wall-rock alteration is less intense than on the neighboring veins.

No ore has been found below the 4,000-foot level. Above that level two large and irregular ore shoots rake to the southwest (to the left looking down the vein). Separate production figures for this vein are not available.

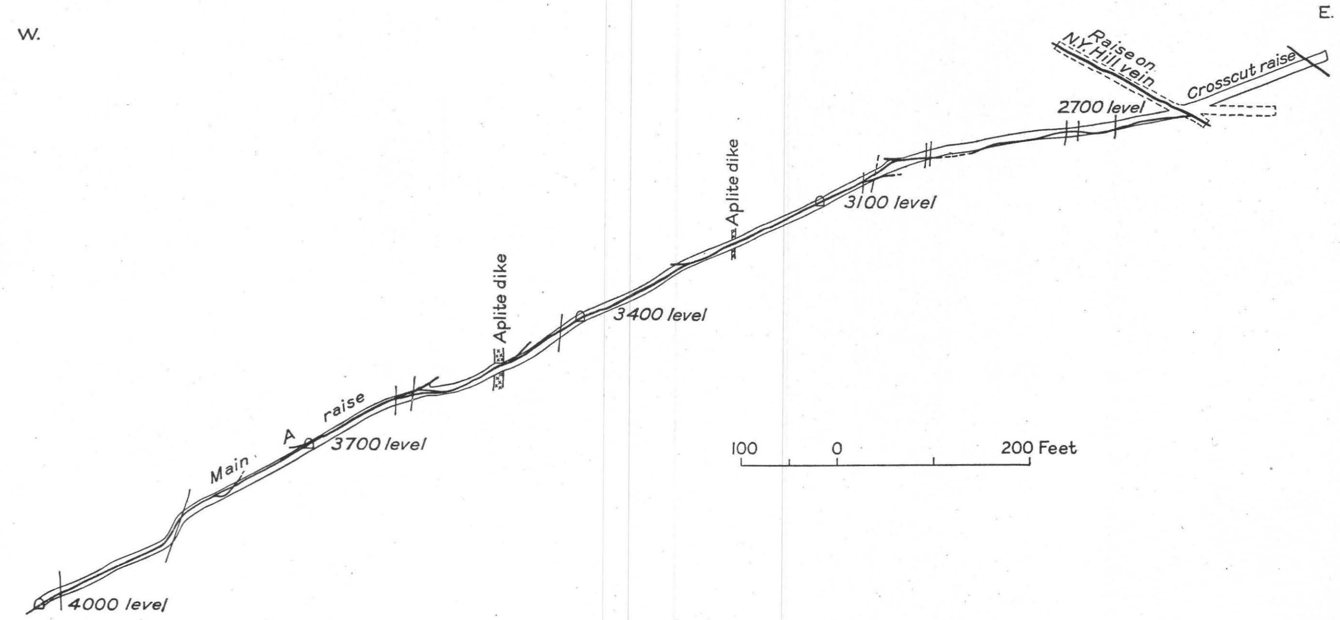


FIGURE 50.—Section through the main A vein raise, North Star mine.

Y VEIN

Attitude and dimensions.—The Y vein strikes east-west and dips south at an average angle of 30°. It has been followed on the 3,700-foot level of the North Star mine for approximately 2,000 feet along the strike and up the dip from the 3,700-foot level for approximately 1,600 feet. Drifts on the Y vein and North Star vein are connected on the 3,700-, 3,400-, 3,000-, and 2,700-foot levels.

Although the general strike of the Y vein is east-west, it has the form of an arc convex toward the hanging wall. The western part of the arc, where the largest and principal ore shoot occurs, strikes N. 75° W., and the eastern part of the arc on the 3,700-foot level strikes N. 70° to 75° E. Dips are variable, but the average in the Y raise is 30°.

Wall rocks.—The greater part of the Y vein as exposed in mine workings lies in diabase and porphyrite. A tongue on granodiorite is cut by the 3,400-foot level, and the 3,700-foot level alternately cuts granodiorite apophyses and diabase roof pendants. Everywhere the contacts are sharp and without transitional zones. At the junction of the North Star and Y veins on the 3,700-foot level the diabase roof pendant is well exposed by the branching workings, and its form can be determined with some confidence. Aplite dikes, striking northeast, cut both the diabase and the granodiorite.

Ore shoots.—About 6,200 feet of drifts have been opened on the Y vein, of which 35.48 percent has been in stoping ground. This is slightly less than the average for the North Star mine. Three ore shoots have been mined (fig. 51). The largest shoot is on the west end of the vein and has been followed from the 3,400-foot through the 2,700-foot level. It has a pitch length of 1,100 feet and a breadth of 600 feet. Two smaller stopes on the eastern part of the vein lie between the 3,700- and 3,400-foot levels.

The Y vein raise was driven 800 feet up the dip above the 2,700-foot level, but little quartz was found.

Z VEIN

The Z vein strikes N. 30° E. and dips about 20° NW. (fig. 51). It lies in the footwall of the Y vein and strikes at right angles to it. Drifts on the Z vein have been seen on the 3,400- and 3,400-foot intermediate levels. Although quartz as much as 12 inches in width occurs in this vein, it was too poor in gold to be mined.

NEW YORK HILL VEIN

History and production.—The New York Hill vein was one of the earliest to be mined in the district. Between 1852 and 1865 it produced $500,000, and in 1866–67, 2,189 tons of ore yielded $106,430, an average of $49 a ton. Shortly thereafter mining was suspended, to be resumed in 1874, when the vein produced $100,000 between September 1874 and October 1875. In 1882 the ore averaged $25 a ton.[58] In 1894 the New York Hill mine was purchased by the North Star. After about 6,000 tons yielding $60,000 had been taken out, the mine was again closed and has not been reopened. Hague[59] has estimated the total production of the New York Hill mine as $1,500,000 from 100,000 tons of ore. Between 20 and 25 percent of the ground explored proved profitable.

Attitude and dimensions.—The New York Hill vein strikes northwest and dips northeast, roughly parallel to and above the North Star vein. Its average strike is N. 55° W., and its average dip is 33° NE. As the south end of the vein crops out on a steep hillside the outcrop turns downhill to the east, giving the impression that the strike is more irregular than it actually is.

As shown on the accompanying map (pl. 30), the early work on the vein was done through the Chevanne and New York Hill shafts. On the 400-foot level the vein was followed for 2,000 feet on the strike. It was stoped for 600 feet down the dip in the Chevanne work-

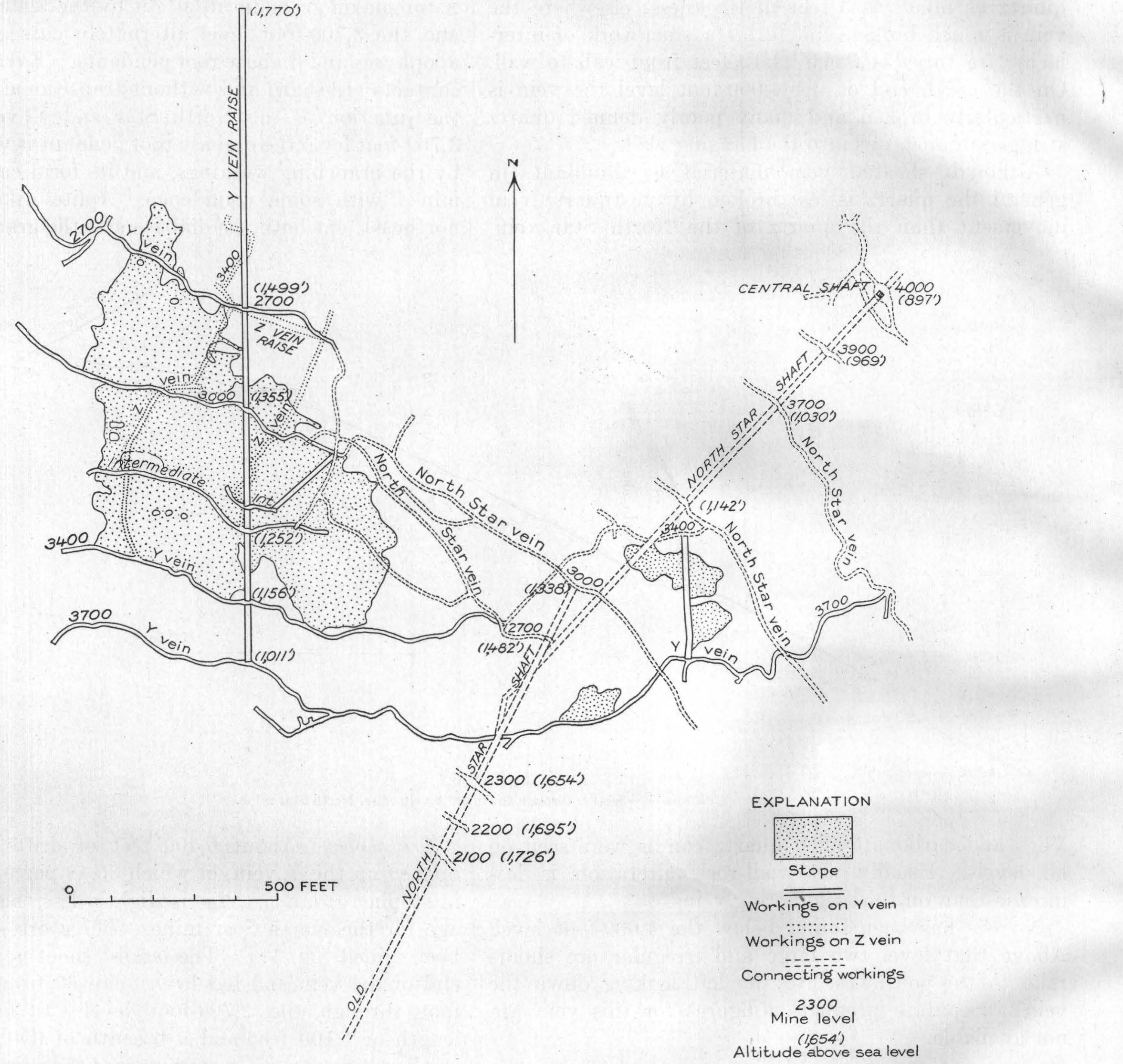
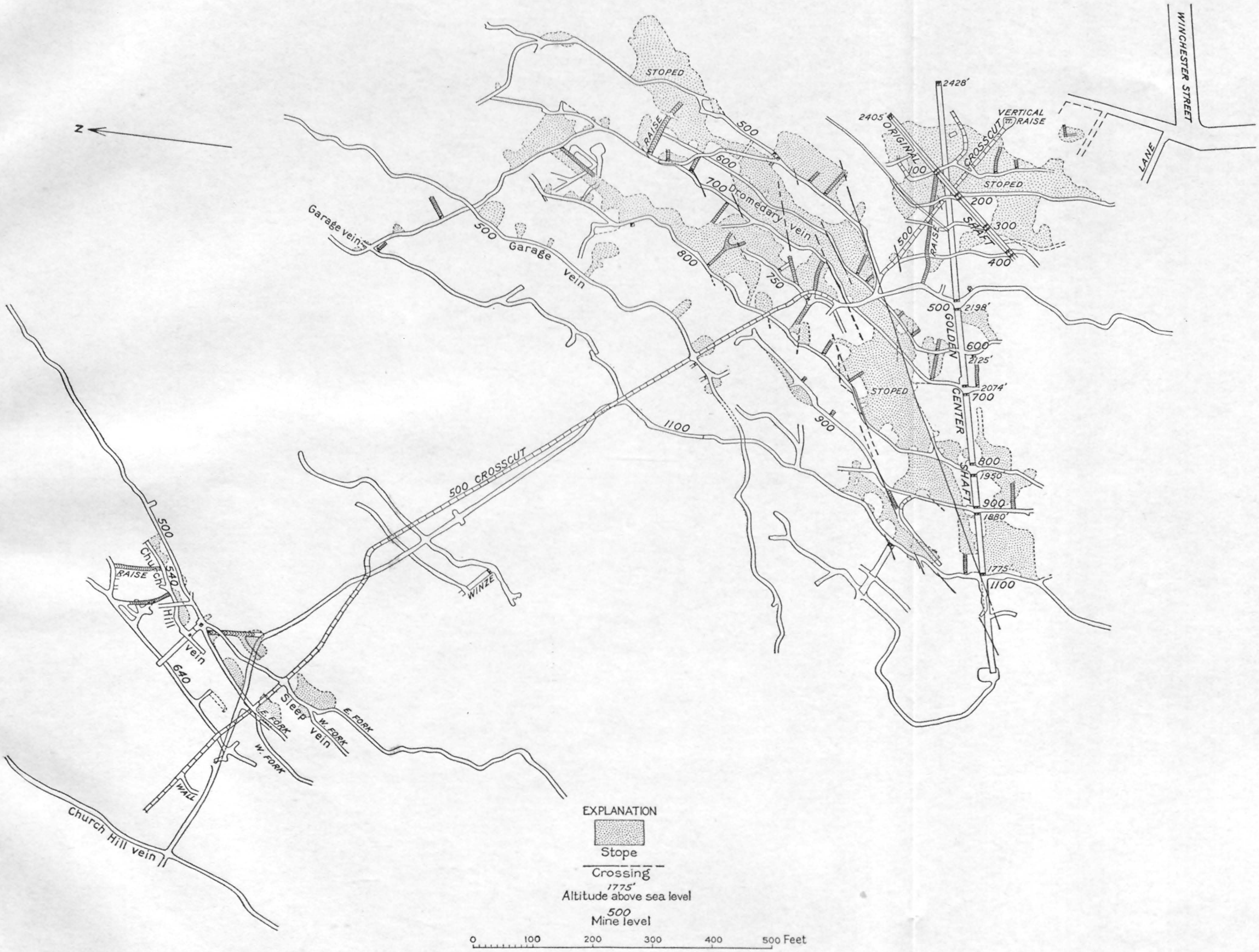


FIGURE 51.—Map showing workings on the Y and Z veins of the North Star mine. Stoped areas are shaded, and connecting workings on other veins are indicated by dashed lines.

[58] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 213.

[59] Hague, William, The North Star mine: Min. and Sci. Press, Oct. 10, 1914, pp. 551–552.



DEVELOPMENT MAP OF THE GOLDEN CENTER MINE, JULY 1934.

ings and 1,300 feet down the dip in the New York Hill shaft.

The central shaft of the North Star mine intersected the New York Hill vein at a vertical depth of 600 feet. Extensive development work established the fact that the vein becomes horizontal and "rolls" at that level, resulting in a double reversal of the dip, as shown in the accompanying section (fig. 52).

Later the A vein on the 3,700-, 3,400-, and 3,100-foot levels was found to end against a northeastward-striking the drift. On the 600-foot level from the vertical central shaft the vein attains a width of 3 feet or more. The quartz is hypidiomorphic, in places comby, and shows little evidence of shearing. That some reopening has taken place, however, is witnessed by plate 8, *D*, where two generations of quartz vein filling are readily recognizable. In the lower levels the vein fracture is generally narrow, and the average width of the quartz vein filling is 6 to 12 inches, with a maximum of 24 inches.

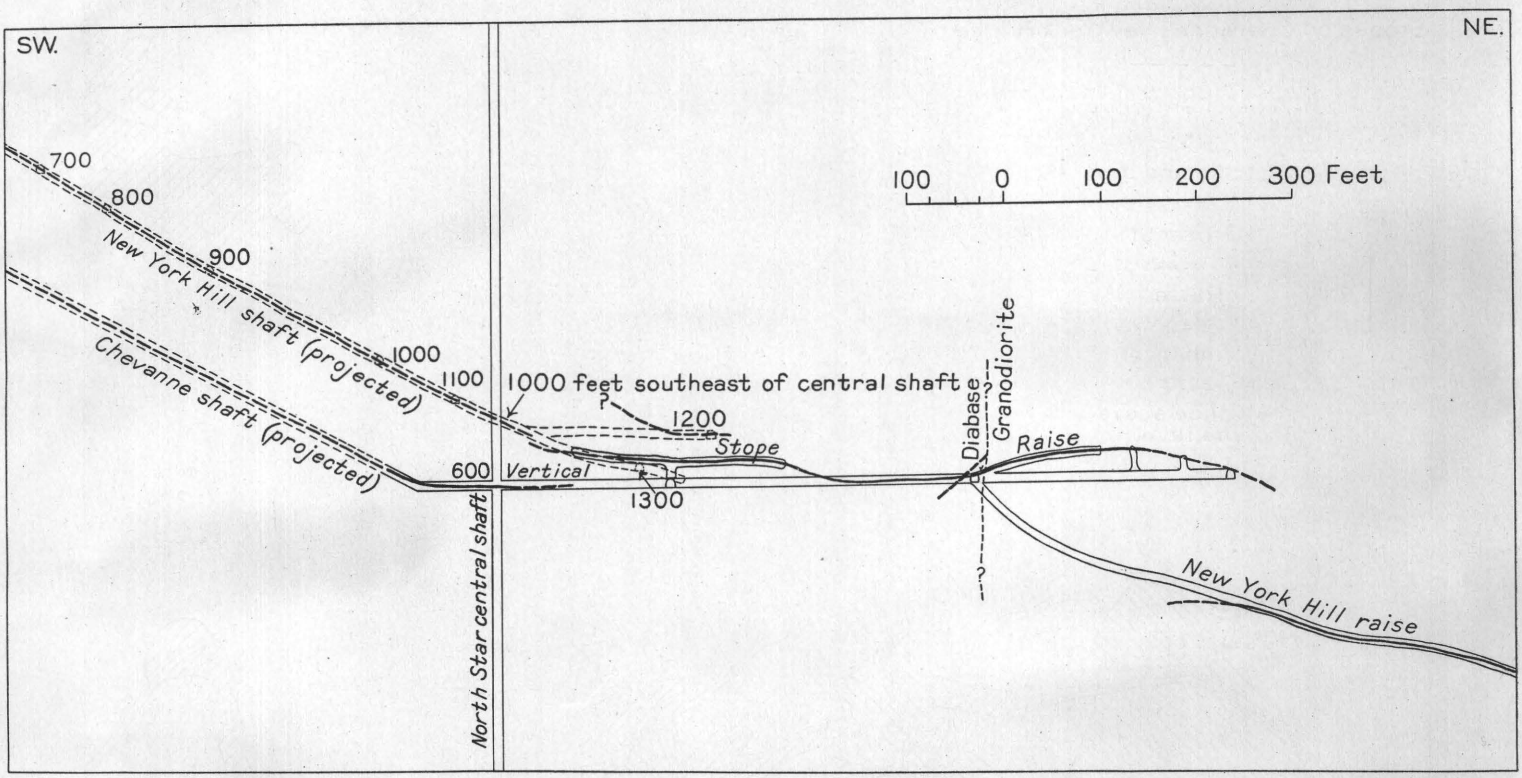


FIGURE 52.—Generalized section through the 600-foot station, central shaft, and the New York Hill raise of the North Star mine, with projections of the New York Hill and Chevanne shafts.

vein which was also cut on the 2,700-foot level in the A raise. A raise from the 3,100-foot level to the 600-foot level established the continuity of the new vein with the New York Hill vein. Below the 600-foot level no productive ground has been found.

All the old workings mined through the Chevanne and New York Hill shafts are in diabase and porphyrite. The granodiorite contact was found on the 600-foot level, and the middle drift on the southern flank in the rolling part of the vein closely follows it. Below the 600-foot level the vein is in granodiorite.

Vein fracture and ore shoots.—In general the New York Hill vein is more uniform in width and structure and has fewer splits and diverging walls than either the North Star or the A vein. Lindgren [60] gave the width of the vein in the old workings, now mainly inaccessible, as between 8 inches and 2 feet. The 400-foot level of the New York Hill shaft was accessible in 1931, and the vein fracture was continuous throughout the length of

[60] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 237.

The outline of the ore shoots is shown on the development map (pl. 30). Those on the Chevanne and New York Hill shafts follow the general rule of the district in raking to the left, down the dip. In the upper stopes the quartz contained between 2 and 3 percent of sulphides and its gold content ranged between 4 and 5 ounces to the ton. Most of the gold was free, and much of it was coarse, forming "specimen" ore. Below the 600-foot level the quartz is narrow, and its gold content is too low to permit profitable mining.

NEW ROCKY BAR VEIN

A part of the workings on the New Rocky Bar vein were accessible in 1930 from the upper levels of the Chevanne shaft. This vein produced much coarse gold in 1880 and 1882 but has not been worked since. Lindgren [61] called attention to the reversal in dip of this vein, and his map and sections are reproduced in figures 53 and 54.

[61] Idem, p. 237.

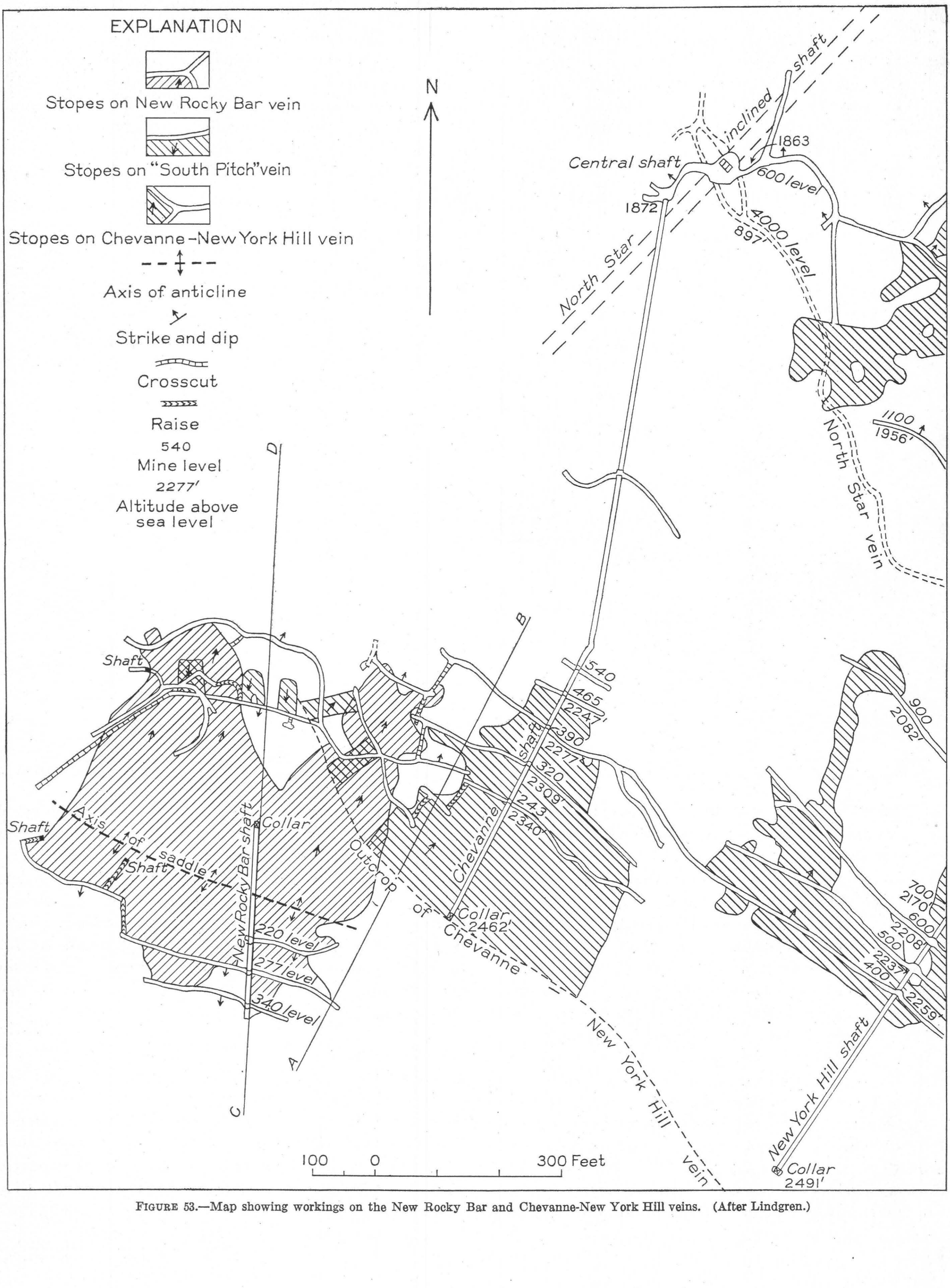
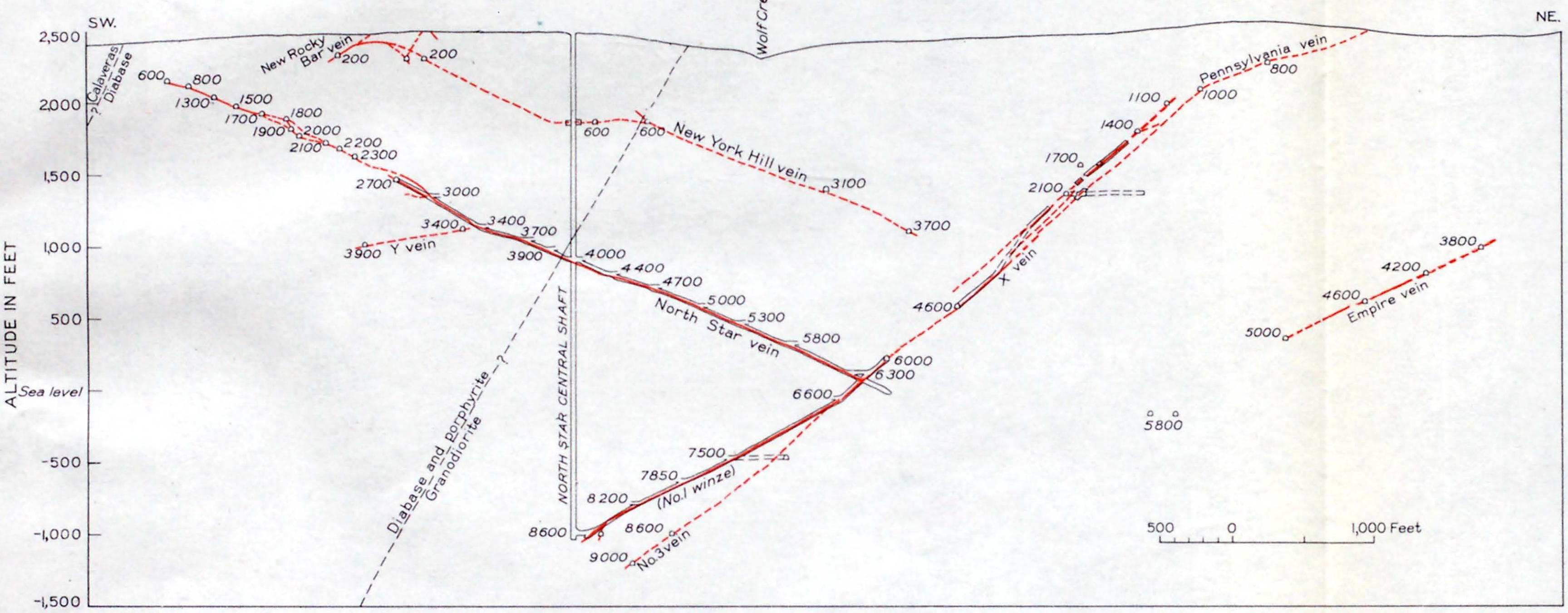
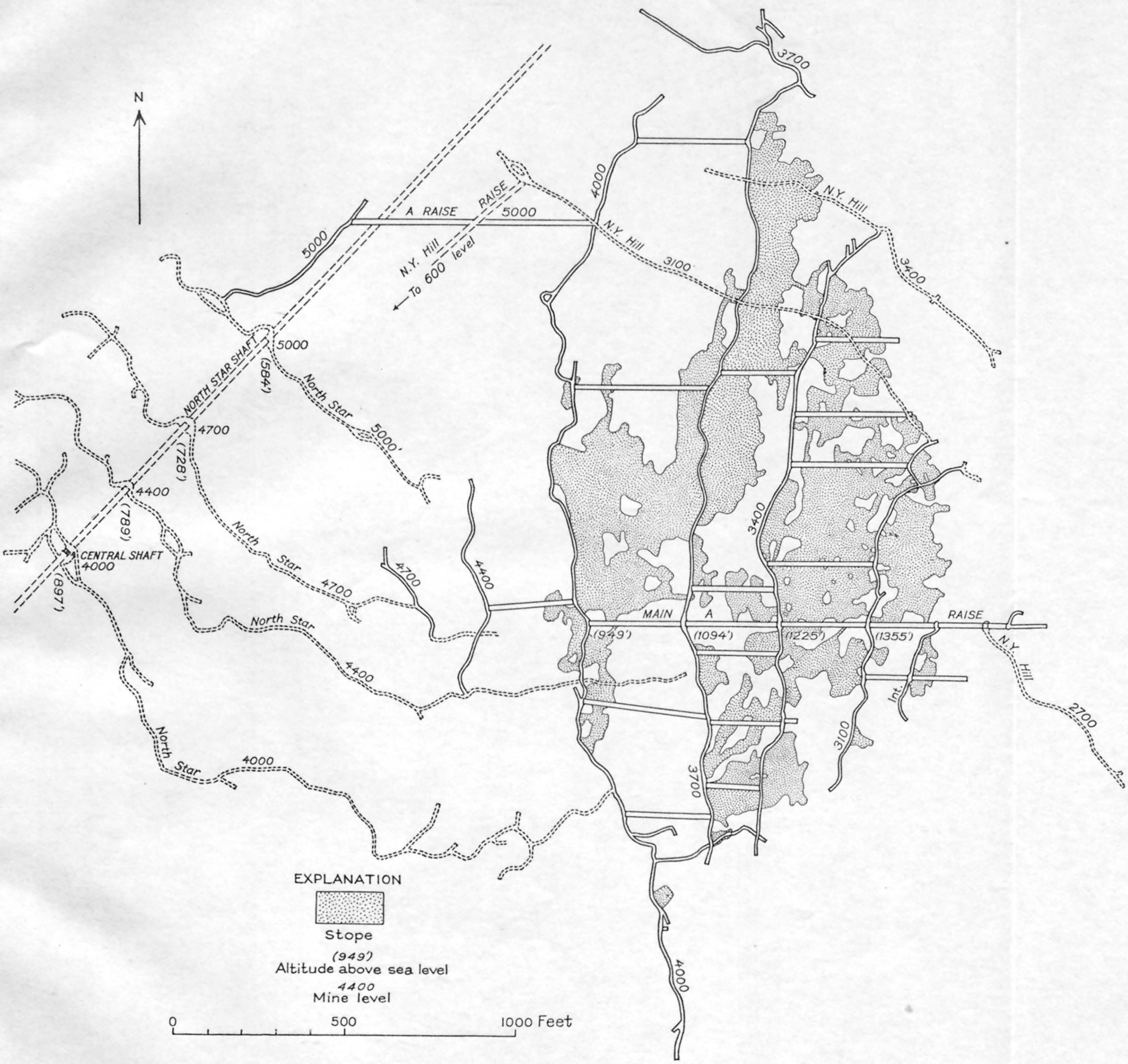


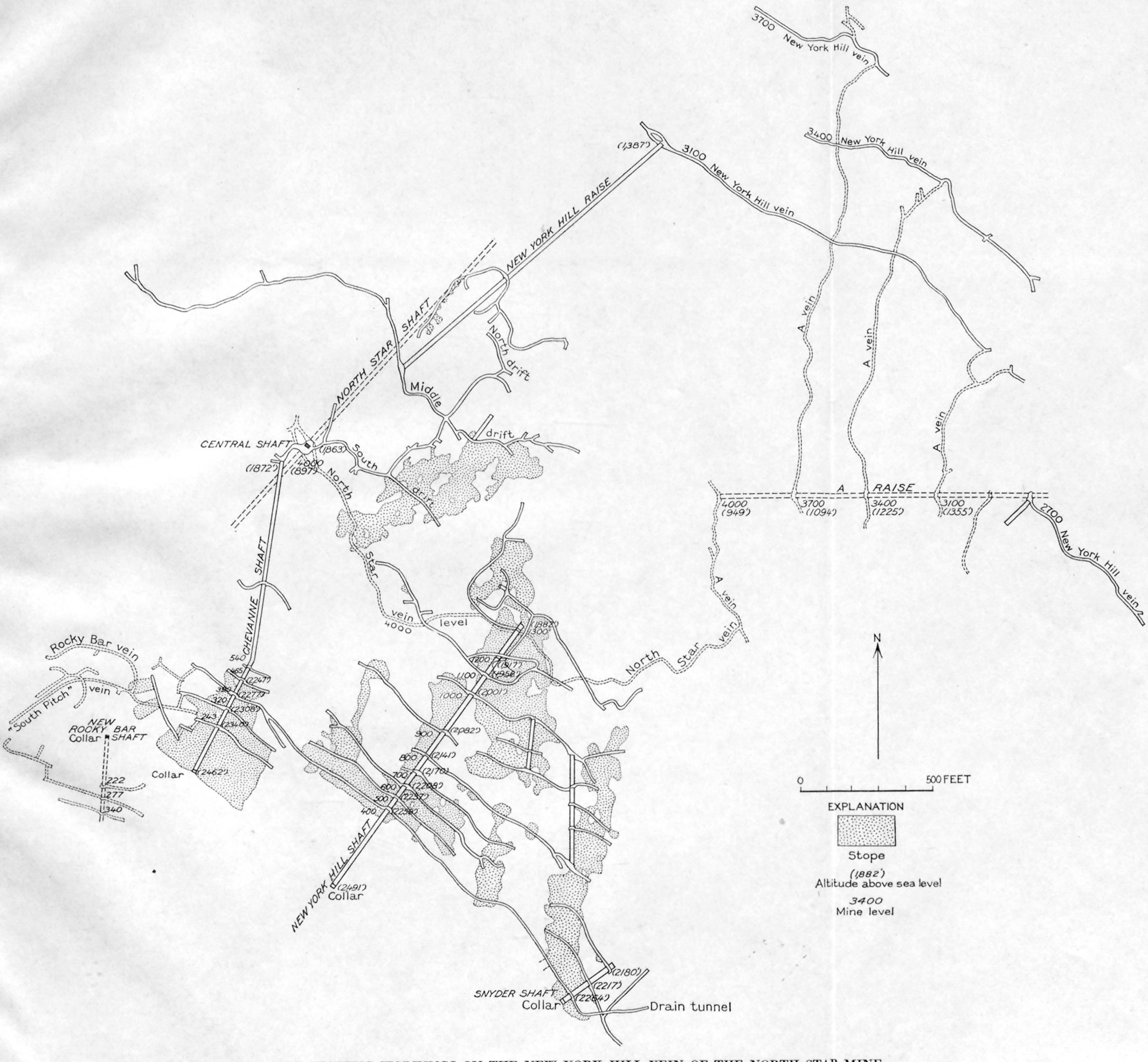
FIGURE 53.—Map showing workings on the New Rocky Bar and Chevanne-New York Hill veins. (After Lindgren.)



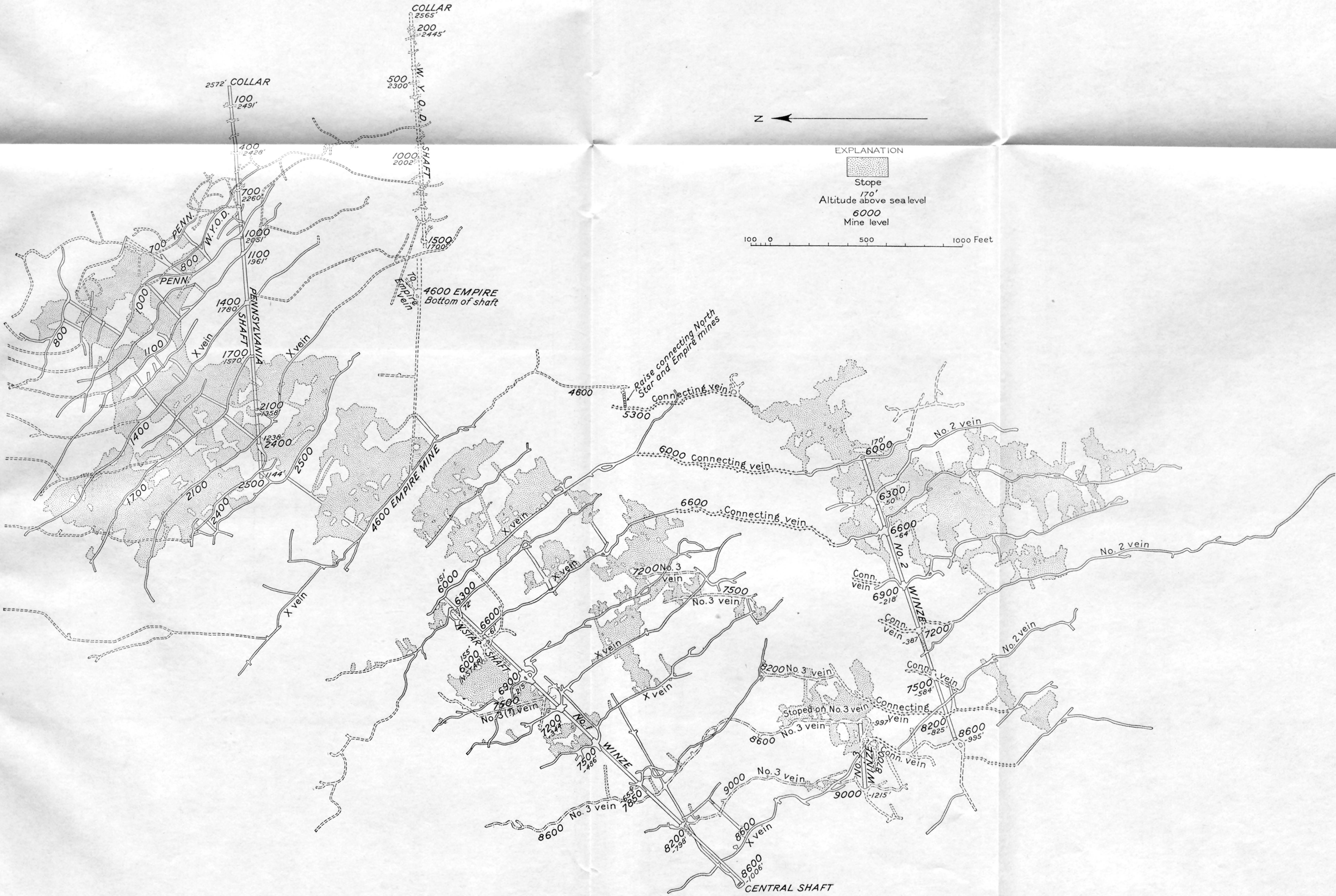
SECTION THROUGH CENTRAL NORTH STAR SHAFT AND No. 1 WINZE



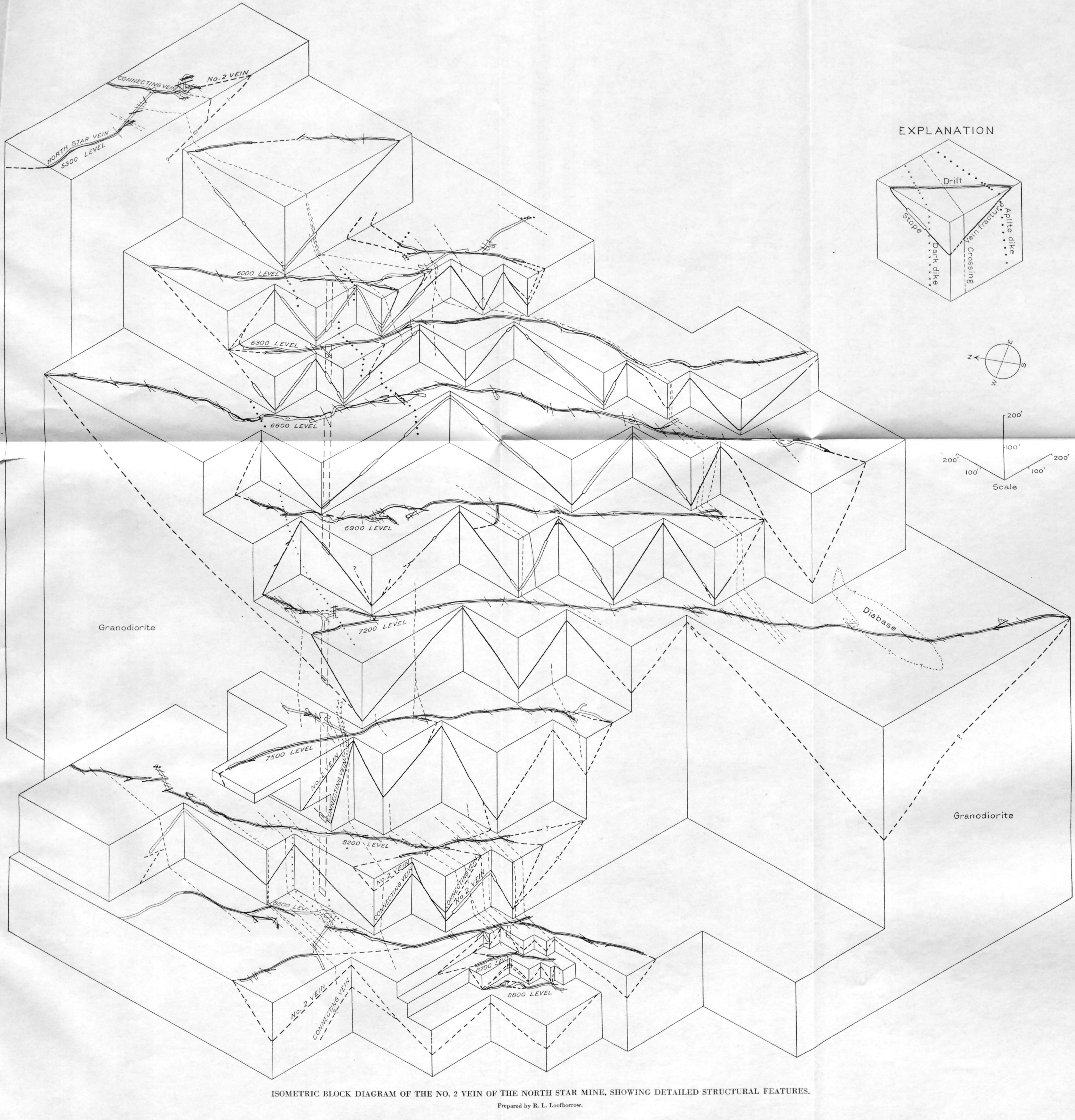
MAP SHOWING WORKINGS ON THE A VEIN, NORTH STAR MINE.



MAP SHOWING WORKINGS ON THE NEW YORK HILL VEIN OF THE NORTH STAR MINE.



MAP SHOWING WORKINGS ON THE X VEIN OF THE NORTH STAR, EMPIRE, AND PENNSYLVANIA MINES AND THE NO. 3, CONNECTING, AND NO. 2 VEINS OF THE NORTH STAR MINE IN 1931.



ISOMETRIC BLOCK DIAGRAM OF THE NO. 2 VEIN OF THE NORTH STAR MINE, SHOWING DETAILED STRUCTURAL FEATURES.

Prepared by R. L. Loofborrow.

X VEIN

Attitude and dimensions.—The X vein (also called the No. 1 vein in the North Star mine) strikes N. 45° W. and dips southwest, conjugate to the North Star vein. It has been explored along the strike for about 2,200 feet and up and down the dip for 4,600 feet. Its average dip is 35°.

The X vein extends up the dip from the 8,600-foot level of the North Star mine to the 700-foot level of the Pennsylvania mine and has been worked from both mines. It has also been worked through a crosscut extending west from the bottom of the Empire shaft on the 4,600-foot level of the Empire mine. The relations of the working to the mine shafts are shown in the accompanying development map (pl. 31) and the block diagram (pl. 32). Although the dip of the X vein is somewhat variable, the strike is conspicuously constant.

The continuity of the vein on the dip is established (1) by the No. 1 shaft of the North Star mine, which follows the vein between the 8,600- and 6,000-foot levels of that mine, (2) by the stopes between the 6,000-foot North Star level and the 4,600-foot Empire level, (3) by the raise from the 4,600-foot level of the Empire to the 2,500 foot level of the Pennsylvania mine, and (4) by the raises and stopes between the 2,500- and 700-foot levels of the Pennsylvania mine. Above the 1,000-foot level of the Pennsylvania shaft there is a complex maze of old workings, most of which are inaccessible so that the course of the X vein has not been determined.

The vein lies wholly in granodiorite.

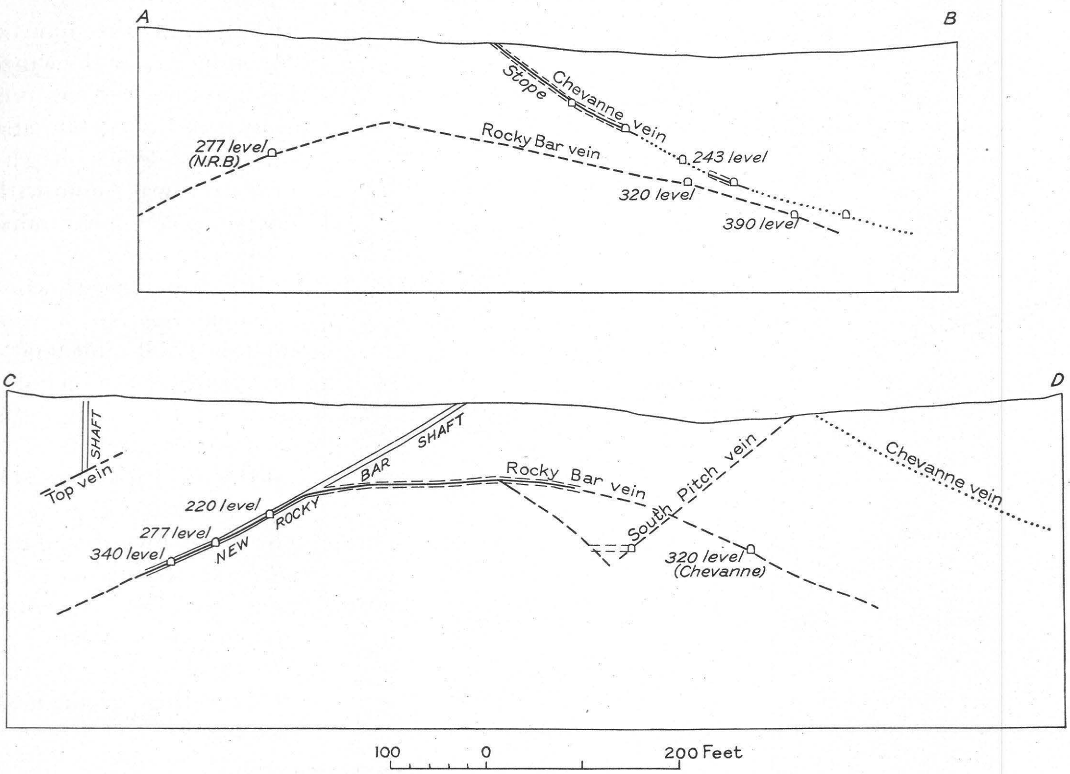


FIGURE 54.—Sections through the New Rocky Bar and Chevanne veins. (After Lindgren.)

Character.—The X vein is characterized by the abundance and persistence of the gouge and breccias within the walls of the vein fracture, necessitating, in places, much closer timbering than is required by other veins in the granodiorite. In contrast to the other veins of the North Star and Empire mines, the X vein is conspicuous in occupying a "strong" fracture. Furthermore, extensive postquartz movement is indicated by gouge seams that cross the quartz from wall to wall and by much crushed and broken quartz that has not been cemented by later vein minerals. In many places on the vein younger gouge seams cut older gouge. Thus recurrent movement is plainly recorded. Figure 18 is a sketch of the X vein on the 6,600-foot level, showing brecciated quartz cut by later gouge. Within a short distance along the vein distinct gouge zones indicate at least four periods of movement.

The width of the main vein fracture is widely variable, ranging from 1 foot to at least 30 feet and averaging between 5 and 10 feet.

Most of the quartz on the vein has been broken in the course of the recurrent vein movements, and strain figures and shearing structures are recognizable in thin section. Much of the quartz is in rough lenses bounded by gouge zones of variable width. Loose quartz breccias, recemented by later quartz and carbonates, are also present and vugs and comb structures were observed in many places.

Ore shoots.—Plate 31 shows the development on the X vein and the connecting workings. In the North Star mine all workings below the 6,000-foot intermediate level, amounting to about 16,300 feet of drifts, were driven on the vein. Of these 22.69 percent was in productive ground. This is well below the average for the mine, which is 36 percent. The ore shoots in general have been unusually patchy. Perhaps the best ore has come from the stope on the 6,900-foot level west of the winze, where the vein has split into two well-marked branches. Below the 7,800-foot level little ore has been found. Above the 6,000-foot level stoping extends to the "compromise line," a vertical boundary which formerly separated the North Star and the Empire properties. Figure 33, A, shows the distribution of gold as determined from car samples in some of the stopes on the 6,600-, 6,300-, and 6,000-foot levels. Column 3 in the table on page 48 shows the variation in value and width of quartz at 5-foot intervals along the vein on the 7,500-foot level. This table serves to show the irregular distribution of the gold.

NO. 3 VEIN

Roughly paralleling the X vein and in its footwall is the No. 3 vein. Most of the development work on this vein has been done on the 8,600- and 9,000-foot levels, but it has also been explored on the 8,200-, 7,500-, and 7,200-foot levels. The structural relations of the No. 3 vein are shown in the block diagram of the Pennsylvania-X vein system (pl. 32), and drifts on the No. 3 and connecting workings on the X and No. 2 veins are shown on plate 31. Figure 55 is a section passing through the X and No. 3 veins.

On the 8,600-foot level the vein is intersected by a crosscut from the central-shaft station into the footwall. The vein at the intersection strikes northwest and dips southwest. Sharp walls with little or no gouge are separated by quartz whose average width ranges between 2 and 12 inches. Halfway between the crosscut and the collar of the No. 3 winze (pl. 31) the strike undulates and changes to north, and the vein is more broken with diverging walls and some gouge. Just south of the winze the vein is cut off by the X vein. Near the crosscut a basic dike striking northeast, at right angles to the drift, has not been displaced by the vein, whereas on the 9,000-foot level a second basic dike is displaced 3 feet horizontally.

The quartz is principally hypidiomorphic-granular, with less of the sheared and ribbon textures than is common in other veins in the mine. Combs are common, and vugs with cavities as much as 1 inch in diameter have been observed on the 9,000-foot level. The scarcity of sheared quartz and heavy gouge and the sharpness and unbroken character of the vein walls indicate the absence of appreciable postquartz movement, a conclusion that is further substantiated by the fact that much of the quartz is tightly "frozen" to the vein walls.

Pyrite is fairly abundant in the ore, galena is relatively scarce, and a light-yellow sphalerite is sparsely distributed on the 9,000-foot level. Although the vein is generally narrow, and the gold is irregularly distributed in the quartz, the stope above the winze has produced good ore. Between the 8,600- and 8,700-foot levels high-grade ore was found with coarse gold surrounded by calcite.

It is possible that what is called the No. 3 vein on the 8,600- and 9,000-foot levels really includes parts of two veins—the segment that strikes northwest underneath the No. 1 winze, and the northward-striking segment that is exposed near the No. 3 winze and may be a downward continuation of the "Connecting" vein, next described.

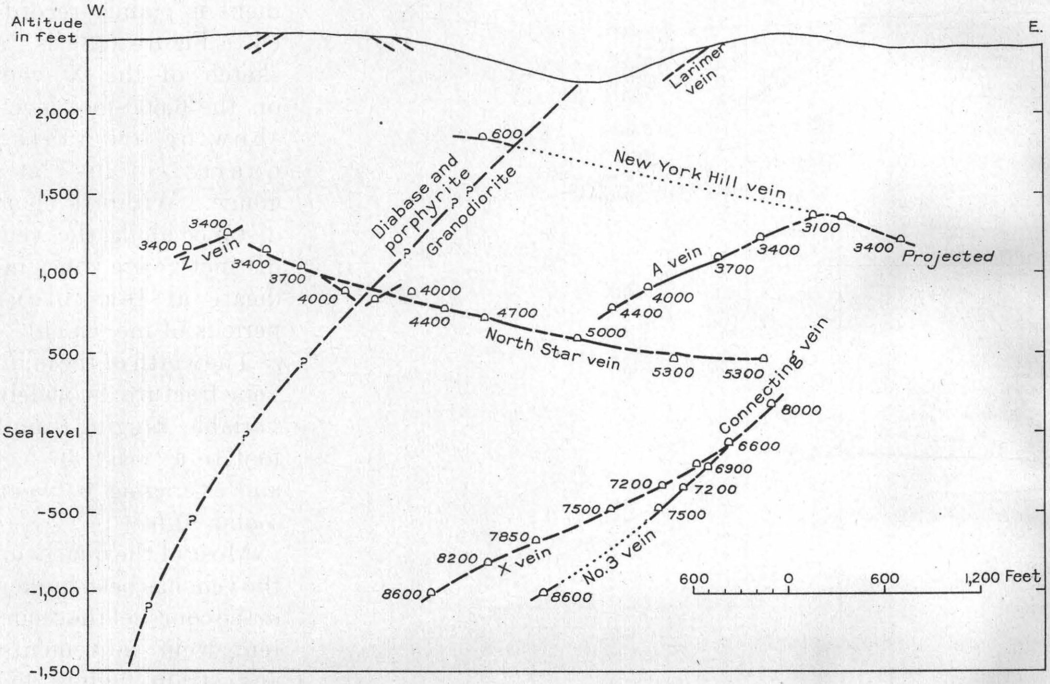


FIGURE 55.—East-west section 240 feet north of the central shaft, North Star mine.

CONNECTING VEIN

In the 6,000-foot level drift on the X vein about 1,200 feet southeast of the collar of the No. 1 winze (pl. 31), a tight, narrow, barren fracture striking to the south leaves the X vein. A drift was driven on this unpromising fracture and revealed little change in width or tenor, but 800 feet from the X vein a new vein, later known as the No. 2, was found. Because the barren fracture was the cross-over connecting two strong veins, it was named the "Connecting" vein. Later the 6,600-foot drift was driven from the X to the No. 2 vein and the Connecting vein was later explored from the No. 2 winze on all the deeper levels, but no ore was found.

In places on the 6,000- and 6,600-foot levels the Connecting vein is marked by a single tight crack bordered by a narrow band of altered granodiorite.

Commonly, visiting mining engineers and geologists are surprised at the amount of drifting that has been done on such tight and apparently unpromising fractures. The reason is that many times, in the history of the camp, weak veins such as the Connecting vein have led to productive veins or have themselves become productive.

NO. 2 VEIN

The No. 2 vein, like the X and No. 3, strikes north to northwest and dips west. It has been followed only in lower parts of the North Star mine from the 6,000- to the 8,600-foot level, where it has been the most profitable vein worked in recent years.

Developments on the vein up to 1932 and wall rocks and general structural relations to other veins are shown in plate 31, and the detailed structure is shown in the block diagram of the No. 2 vein (pl. 33). Plate 34 is a section through the No. 2 winze.

As previously stated, the No. 2 vein was discovered by drifting on the 6,000-foot level along the barren Connecting vein. When its value was established, the vein was opened from the 8,600-foot level, and a winze between the two levels was driven. Levels were turned as shown on plate 31, and much of the vein south of the winze was later stoped. Work has systematically been extended southward, where the strike of the vein turns to the southeast. The average dip of the entire vein is about 35°, though the dips of individual walls and vein segments vary widely from this average.

The wall rock is granodiorite except on the 7,200-foot level about 1,700 feet south of the winze, where the drift passes through diabase for 200 feet. As diabase has not been found on levels either above or below and as the main diabase-granodiorite contact dips west, the diabase encountered on the 7,200-foot level appears to be a large inclusion in the granodiorite.

The thickness of the vein ranges from 1 to 10 feet. Some gouge is always present, but its amount and distribution vary. In some places it is confined to one wall, in others it is on both walls, and commonly gouge seams of variable width cut the quartz vein-filling.

A partial measure of the displacement of the vein fracture is afforded by the offset of a quartz-filled crossing, exposed in the main raise above the 6,000-foot level. There the hanging wall has been thrust over the footwall with a reverse displacement of 12 feet in the plane of the raise. As strong mullions on the walls strike N. 40° E., the net displacement is about 20 feet.

All types of quartz are present in the vein. The most conspicuous combs seen anywhere in the district were found on the 6,000-foot level about 300 feet south of the shaft (pl. 9, *A*), where they graded into massive white quartz. Vugs a foot or more in diameter (pl. 15, *A*) were observed on the 6,300-foot level north of the shaft. Commonly, however, the quartz shows evidence of shearing, and banded textures predominate.

The vein was followed above the 6,000-foot level by a series of raises and intermediate levels until the cost of rehandling the ore made mining unprofitable. North of the winze the characteristic regularity of the vein is lost in a series of barren splits and reverse-dipping fractures best exposed on the 5,300-foot level, which has been extended from the North Star vein.

After 1931 drifting to the south on the 8,600-foot level of the No. 2 vein was continued, and about 2,500 feet due south of the No. 2 winze a new vein called the Charles David was found. This vein strikes N. 70° W. and dips at an average angle of 40° SW. Up to August 1934 it had been followed for 1,200 feet on the 8,600-foot level. As drifts to the south along the No. 2 vein on the 7,500-, 7,200-, 6,900-, and 6,300-foot levels had also encountered the new vein, a raise along it was being driven from the 8,600- to the 7,500-foot level. The junction of the No. 2 and Charles David veins on the 7,500-foot level is vertically beneath the collar of the Omaha shaft.

The new vein ranges in thickness from 1 to 5 feet. The quartz is both massive and ribboned. It differs from other veins in the mine in having a higher silver content. Assays of the vein material on the 8,600-foot level show a silver-gold ratio of 3 to 1, whereas the ratio for the adjoining No. 2 vein is about 1½ to 1. This vein appears to be the most promising new discovery in the deep workings of the North Star mine.

MINES ON THE OMAHA VEIN SYSTEM

The Omaha system of veins in the southwest quadrant of the quadrangle comprises a group that strikes north and dips west and lies wholly in granodiorite. It includes the Omaha, Lone Jack, and Homeward Bound, Wisconsin, Hartery, Surprise, Allison Ranch, Mary Ann-Phoenix, and several other veins. As all the mines on the veins, except the Phoenix, which was reopened in 1933, were closed and their shafts caved and filled with water during the time spent in the district, the following mine descriptions are, in the main, brief summaries of the earlier literature, with some additional information obtained from later mine maps.

OMAHA, LONE JACK, AND HOMEWARD BOUND MINES

General features.—The Omaha, Lone Jack, and Homeward Bound shafts are all on the same vein, which has been followed along the strike by drifts for a distance of 3,500 feet and down the dip in the Omaha shaft for 1,400 feet. The average dip is 33°.

The Lone Jack mine was located in 1855. In 1885 the Omaha, Lone Jack, and Homeward Bound mines were joined under the name of the Omaha Consolidated Mining Co. From 1890 to 1899 the Omaha Consolidated produced 54,966 tons of ore valued at $883,970, an average of $6.17 a ton. In 1903 the Empire West Mines acquired the group. In 1906 the mines were shut down, and they have not since been reopened. MacBoyle[62] estimated the total production of this group of veins together with the Wisconsin mine of the Menlo Mining Co. to be $3,500,000.

[62] MacBoyle, Errol, Mines and mineral resources of Nevada County, p. 163, California State Mining Bureau, 1919.

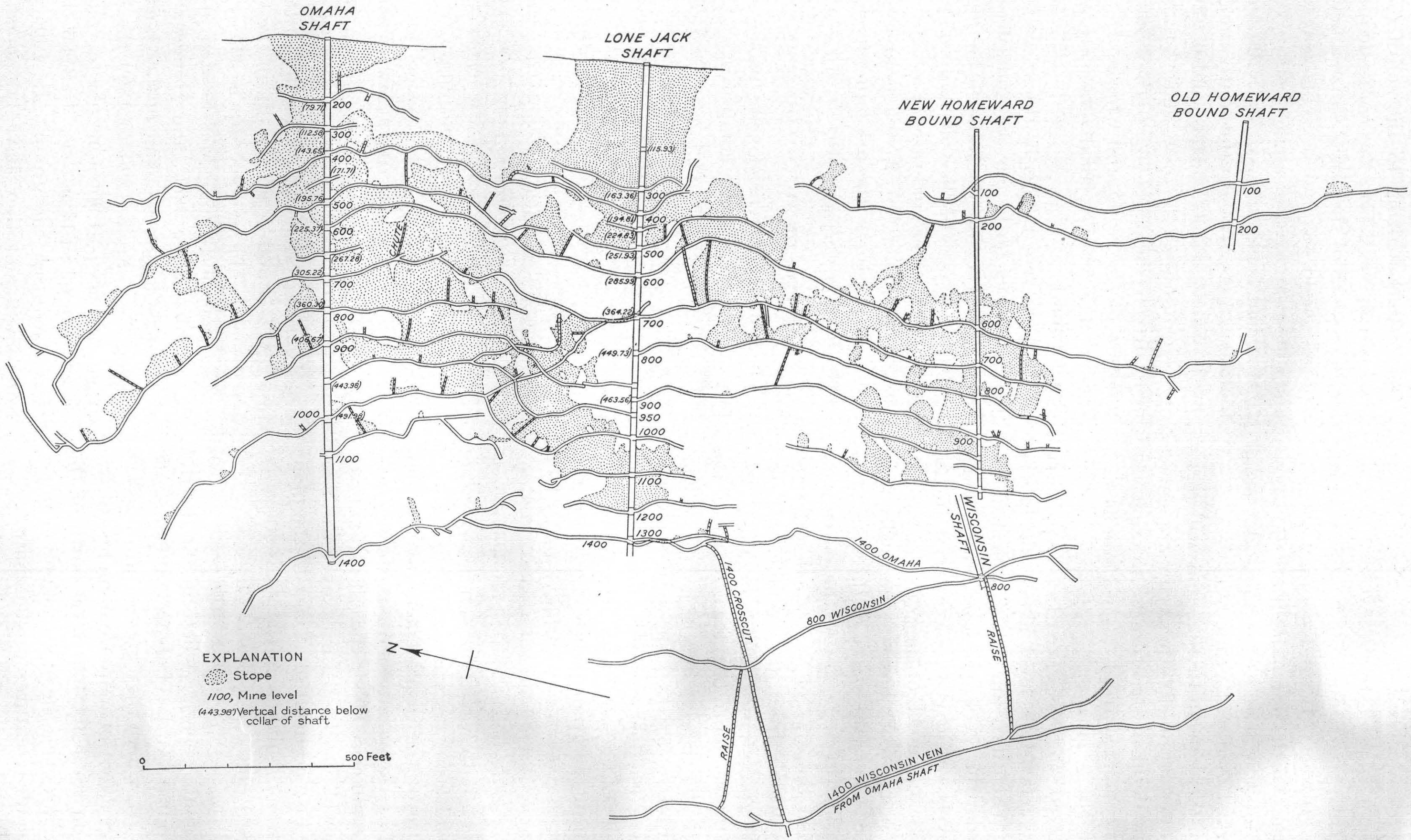


FIGURE 56.—Development map of the Omaha, Lone Jack, and Homeward Bound mines. Stoped areas are shaded. The figures give the vertical distance below the collar of the Omaha shaft.

Figure 56 is a development map of the group. Approximately 34,000 feet of drifting has been done on the Omaha vein, of which 11,000 feet, or 32 percent, was through stoping ground. The Omaha mine is connected with the Wisconsin mine by a crosscut on the 1,400-foot level, where the Wisconsin vein lies 240 feet west and in the hanging wall of the Omaha vein.

Geology.—The Omaha vein is reported to average 1 foot in width, which is somewhat narrower than is common in the district. Hanging and foot walls are in general sharply marked, though sheeting parallel to the walls is present in some places. Quartz is confined to the ore shoot and is principally massive, with little ribboning or shearing. This character, with the narrowness of the vein, is taken to indicate that little or no postquartz movement occurred and, possibly, that there were fewer pulsations of quartz deposition than is common in the district.

Pyrite and galena are the principal sulphides, making up about 4 percent of the ore The concentrates range between $460 and $350 a ton in value and contain, by weight, twice as much silver as gold. The average value of the ore from the stopes on the upper levels was $20 to $30 a ton.

Although the wall rocks contain pyrite, they are less altered by the introduction of carbonate and sericite than is general in the district.

North of the Omaha shaft all levels enter diabase, and the vein turns to the northwest and is dissipated in a series of small fractures, due possibly to the same strong crossing fractures that interrupt the North Star vein at a greater depth. Near the diabase-granodiorite contact are several dikes of quartz porphyry similar to those cropping out in Wolf Creek near the Omaha shaft and exposed underground in the North Star mine.

HARTERY MINE

The Hartery mine is south of the Homeward Bound mine and is probably on a southward continuation of the Omaha vein. It was worked to an inclined depth of 400 feet and about 600 feet on the strike. Located in 1853, the mine was among the early producers in the district. It was worked at intervals up to 1893 and has been idle since. MacBoyle[63] estimated the total production as about $350,000.

The Hartery vein dips at an average angle of 30° W. and, like the Omaha vein to the north is completely enclosed in granodiorite and averages about 1 foot in width. The average gold content of the ore is reported to have been 1½ ounces to the ton, mainly in free gold, with scattered bunches of high-grade ore. The sulphides are sparse and poor.

A parallel vein a short distance to the east and in the footwall of the Hartery was explored to a depth of 500 feet on the incline by the Hartery Consolidated shaft, but no information about the width or gold content could be obtained.

[63] MacBoyle, Errol, op. cit., p. 185.

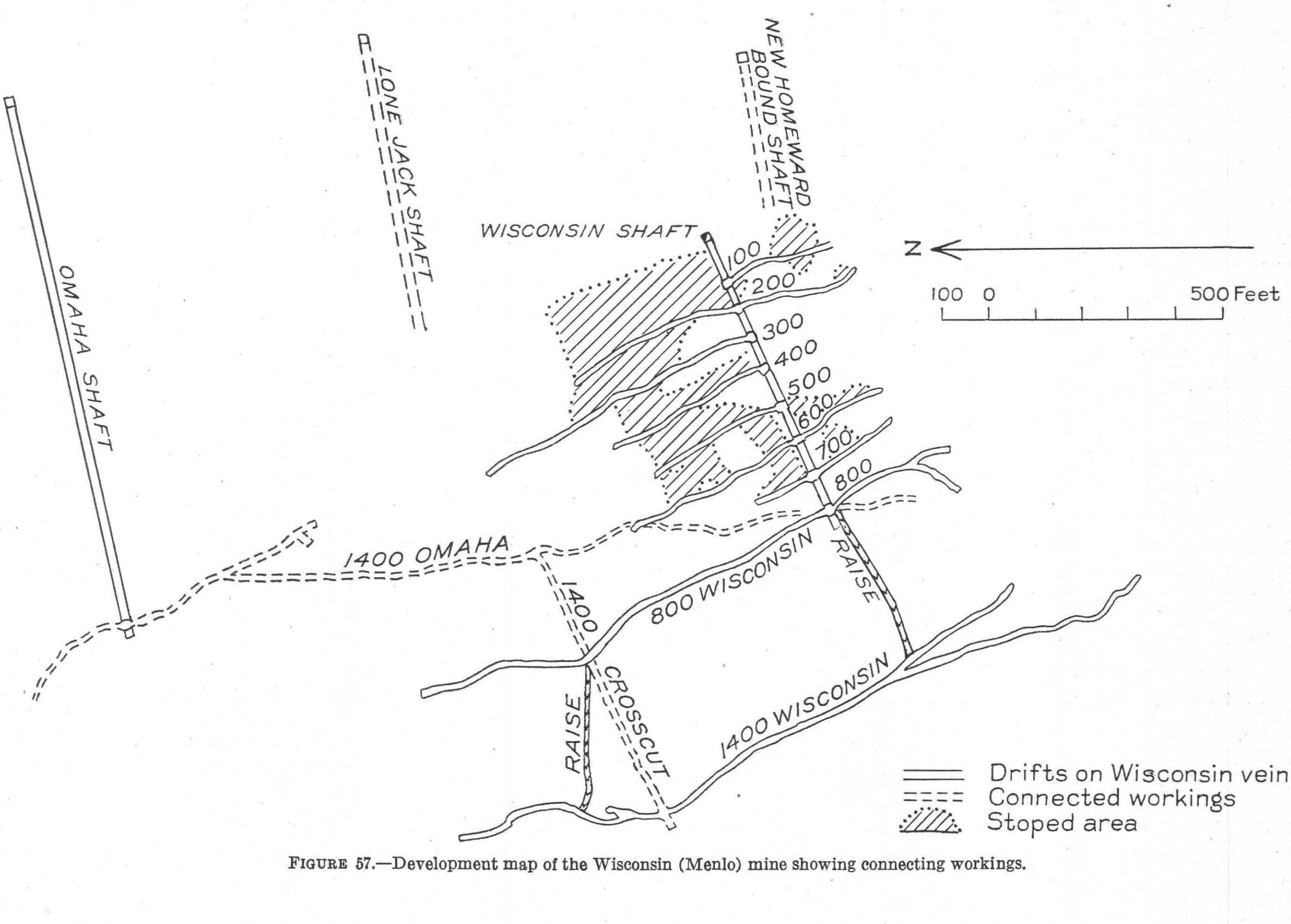


FIGURE 57.—Development map of the Wisconsin (Menlo) mine showing connecting workings.

WISCONSIN MINE

The Wisconsin-Illinois vein (also known as the Menlo vein) lies to the west in the hanging wall of the Omaha vein and is roughly parallel to it. First worked in 1854 to 1856, the mine was reopened in 1866 to 1870, and in the period 1890 to 1900 the Menlo Mining Co., deepened the shaft to 800 feet on the incline (fig. 57). From 1903 to 1906 the property was worked by the Empire West Mines Co., which also owned the Omaha, Lone Jack, and Homeward Bound mines. A crosscut on the 1,400-foot level of the Omaha mine was run from the Omaha vein to the Wisconsin-Illinois vein (fig. 56), and a raise was driven from the south end of the 1,400-foot drift to the 800-foot level near the Wisconsin shaft. Thus the continuity of the Wisconsin vein to the 1,400-foot level was established.

Like the Omaha, the Wisconsin-Illinois vein is narrow, averaging 1 foot in width. The average gold content of the ore in the upper level was around 1½ ounces to the ton, and the average gold content of concentrates, which made up 4 percent of the ore, was about 4½ ounces to the ton. The vein lies wholly in granodiorite.

The Surprise shaft is located on the Minnesota vein, possibly a southward continuation of the Wisconsin vein. It has not been worked for many years.

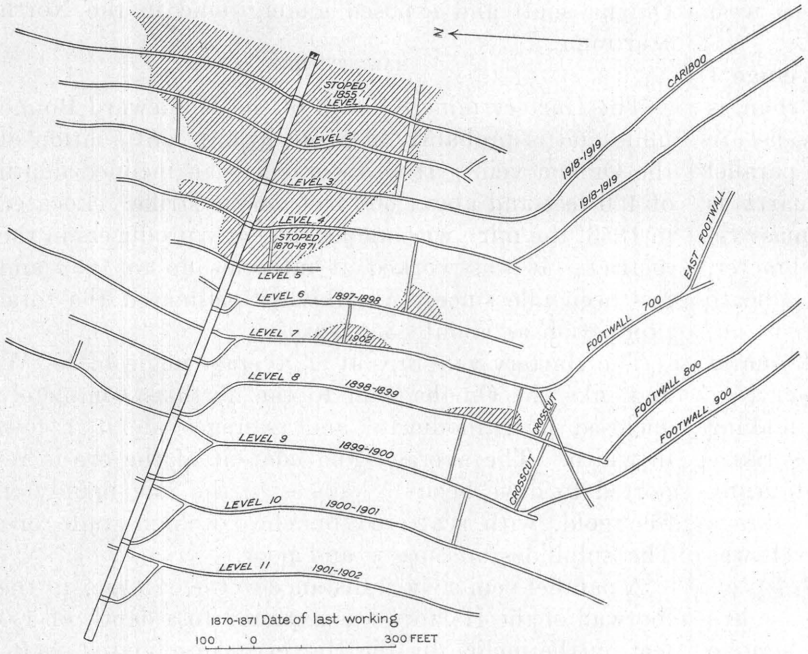


FIGURE 58.—Development map of the Allison Ranch mine. Stoped areas are shaded.

ALLISON RANCH MINE

South and a little east of the Omaha is the Allison Ranch vein, which strikes north and dips at an average angle of 45° W. It was discovered in the early fifties and located in 1854. The mine was one of the principal producers in the period 1854–66, when 46,000 tons of ore averaging 2½ ounces to the ton was mined. The mine was closed in 1866 and reopened in 1869. From April 1869 to December 1871 the production was between $200,000 and $250,000. The mine was again reopened in the periods 1896–1903, 1918–21, and in 1926. It has since been idle.

Like the other westward-dipping veins of the Omaha group, the Allison Ranch vein is narrow, averaging 2½ feet in the upper levels and 1 to 1½ feet at depth. As shown in the development map (fig. 58) most of the stoping was done above the fifth level.

A footwall split, known as the Cariboo vein, which strikes northwest, contains 4 to 10 inches of quartz yielding some rich ore carrying 10 to 15 ounces of gold to the ton. Pyrite, galena, and chalcopyrite were the principal minerals. Both the Allison Ranch and Cariboo veins lie wholly in granodiorite.

PHOENIX MINE

The Mary Ann-Phoenix vein is 2,000 feet west of the Allison Ranch mine and belongs to the Omaha vein system. Some work was done on the vein in the early seventies. In 1932 the mine was reopened under the management of Mr. T. S. Davey, and a vertical shaft 200 feet deep and a winze following the vein to a vertical depth of 400 feet were sunk. A map showing

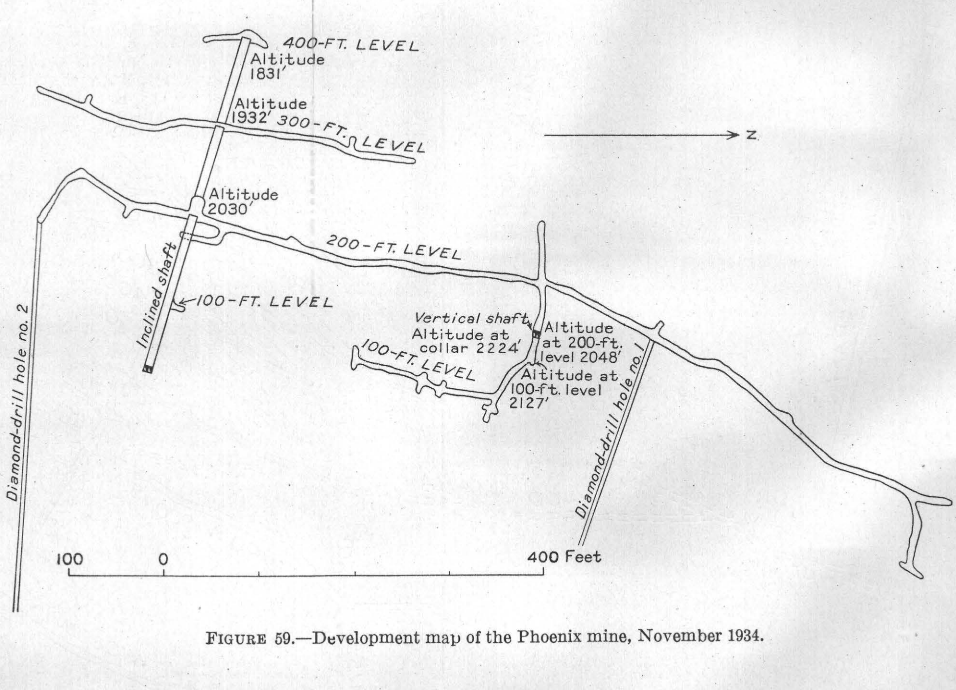


FIGURE 59.—Development map of the Phoenix mine, November 1934.

development in November 1934 is given in figure 59. The mine has since been closed.

The mine lies wholly in granodiorite. A greenstone dike striking northwest and dipping 20° NE. is exposed on the 100-foot level, and similar dike rock is exposed on the 200-foot level and was encountered in the two diamond-drill holes in the footwall of the Phoenix vein. A single aplite dike is also exposed in the 200-foot level.

The Phoenix vein strikes a little east of north and dips at an average angle of 45° NW. Like all the veins of the granodiorite area, the fracture zone is complex and contains many individual fractures with undulating dips ranging from 25° to 80° and locally varying strikes. The distance between the principal vein walls, as defined by the enclosed highly ankeritized granodiorite, ranges between 2 and 18 feet.

The quartz ranges from a thin seam to a vein 3 feet or more thick. Though most of the quartz is of the massive milky type, comb quartz and sheared and brecciated quartz are present.

The distribution of gold in the quartz is erratic. Assays range from a few cents to $100 or more to the ton. The thickness and assay values of a part of the vein on the 200-foot level are shown graphically in figure 31.

A second vein lying in the footwall of the Phoenix vein is exposed on the north end of the 200-foot level and was encountered in the diamond-drill hole at the south end of the level.

OTHER VEINS OF THE OMAHA SYSTEM

Lindgren's map shows a number of other veins striking north and dipping west in the vicinity of the Omaha and Allison Ranch mines, but little is now known about them.

VEINS ON THE EAST SIDE OF THE GRANODIORITE AREA

SOURCES OF INFORMATION

Extending from the town of Grass Valley southeastward to the end of Osborne Hill are a series of northward- to northwestward-striking veins that dip 35° W. This vein group includes the Pennsylvania and Empire mines and several older mines, now inactive. South of the Pennsylvania all the veins crop out in diabase and dip toward the granodiorite contact. The mines at the north end of the group enter the granodiorite in depth, but those at the south end do not reach it.

Only the Pennsylvania, Empire, and some connected workings of the W. Y. O. D. and Rich Hill mines were open during the field seasons spent in the district. Through the courtesy of the Empire Co., maps of the abandoned mines were obtained, and the following descriptions of the mines that are no longer accessible are based, to a large degree, upon information given on those maps.

PENNSYLVANIA MINE

History and production.—The Pennsylvania vein was discovered in 1870, and the Pennsylvania claim was patented in 1879. By 1890 an inclined shaft 345 feet in depth had been sunk and 1,500 feet of drifts and crosscuts opened. By 1898 the shaft had been deepened to 700 feet and the drifts extended to a total of 3,000 feet. In 1890 an apex suit was begun by the Grass Valley Exploration Co., owners of the adjacent W. Y. O. D. mine, against the Pennsylvania Mining Co., and the Pennsylvania brought a counter suit.[64] Much development work was necessitated by the suit, and the resources of both companies were severely drained. In 1902 the court decided in favor of the Pennsylvania Mining Co., and in lieu of damages all the property of the Grass Valley Exploration Co. was awarded to the Pennsylvania.

In 1915 the Empire Mine & Investment Co. purchased the Pennsylvania and W. Y. O. D.

Production of the Pennsylvania and W. Y. O. D. mines, 1898–1909

Year	Ore crushed (tons)	Production	Yield per ton (gold at $20.67 per ounce)	Gold (ounces per ton)[1]
1898	2, 921	$77, 263	$26. 45	1. 28
1899	6, 634	138, 116	20. 82	1. 00
1900–1902	18, 080	245, 247	13. 55	. 65
1903	24, 001	221, 816	9. 24	. 44
1904	26, 082	144, 382	5. 83	. 28
1905	25, 889	167, 346	6. 46	. 31
1906	13, 916	88, 318	6. 34	. 31
1909	42, 935	300, 564	7. 00	. 34
		1, 383, 052		

[1] Approximate figures derived by dividing yield per ton in dollars by 20.67. No allowance is made for silver.

Geological relations.—The principal veins of the Pennsylvania mine are the Pennsylvania and X veins. Developments on the Pennsylvania vein and in the adjoining W. Y. O. D. mine are shown in figure 60, developments on the X vein in the Pennsylvania, Empire, and North Star mines on plate 31, and the relations of the deep workings of the Pennsylvania, Empire, and North Star mines on plate 32, which also shows the general structural and wall-rock relations. Figure 62 is a section through the veins.

The Pennsylvania shaft follows the Pennsylvania vein from the surface down to the 700-foot level. Near this level the shaft intersects the Pennsylvania-X vein junction and continues downward in the footwall of the X vein to the bottom at the 2,500-foot level. In the deep levels the Pennsylvania vein leaves the footwall of the X vein several hundred feet north of the shaft. The relations of the two veins are shown in figure 61.

Both the Pennsylvania and X veins lie wholly within granodiorite.

X vein.—The X vein, which has been worked from the Pennsylvania, Empire, and North Star mines, has been described on pages 77–78. It is characterized by its width, unusually persistent strike, and heavy gouge. Much of the movement has been postquartz. The

[64] Federal Reporter, vol. 117, pp. 509–526, 1902. Lindley, C. H., A treatise on the American law relating to mines and mineral lands, 3d ed., vol. 2, pp. 1482–1490, 1914.

richest part of the vein was found in the Pennsylvania and Empire mines above the 4,600-foot level, where a larger percentage of the total drift length than in the lower levels in the North Star mine was through stopable ore.

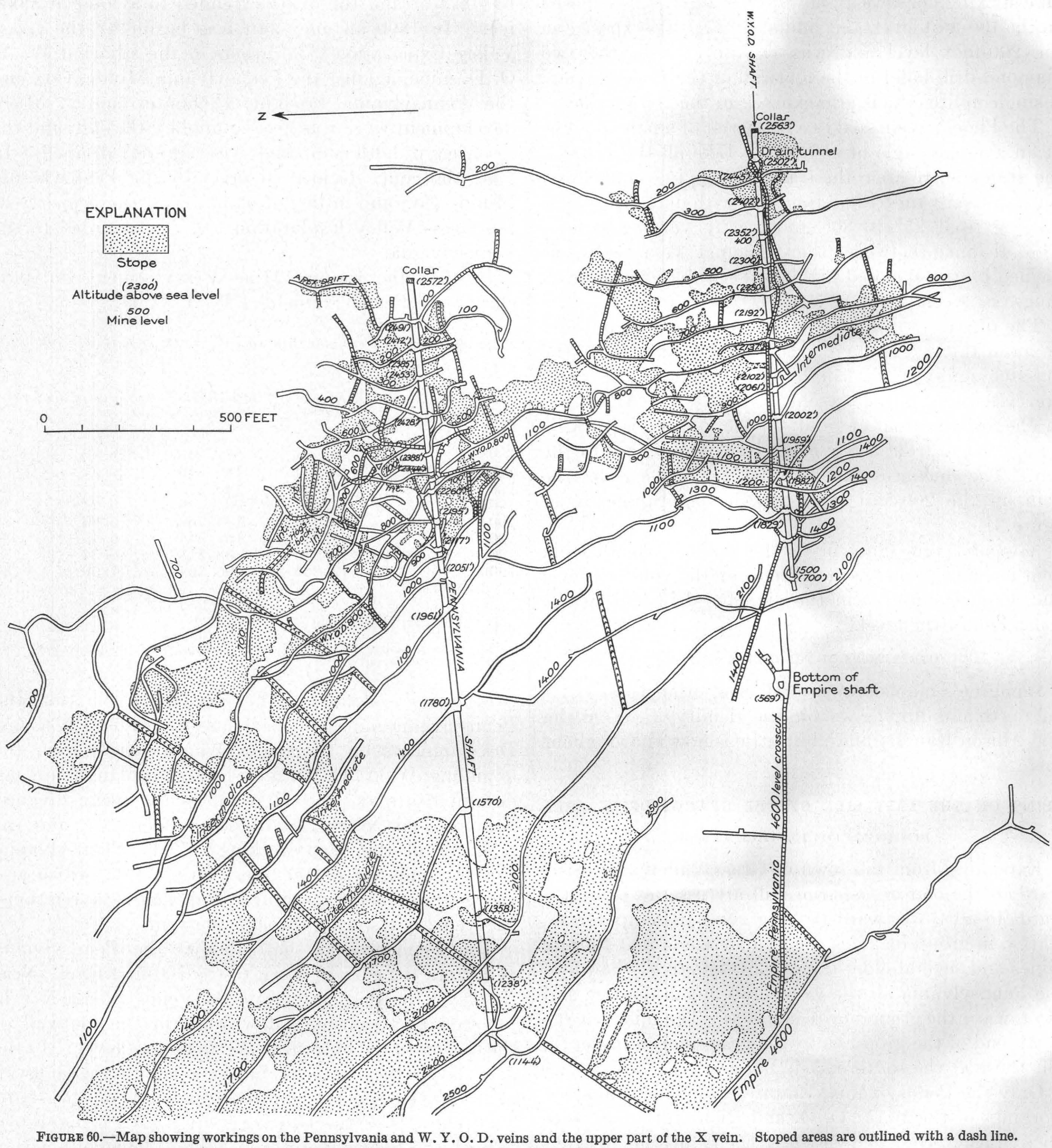


FIGURE 60.—Map showing workings on the Pennsylvania and W. Y. O. D. veins and the upper part of the X vein. Stoped areas are outlined with a dash line.

Pennsylvania vein.—The Pennsylvania vein strikes north and dips at an average angle of 40° W. Lindgren traced the outcrop for 1,000 feet north of the shaft but was unable to trace it to the south. On the 1,000-, 1,100-, 1,400-, 1,700-, and 3,400-foot levels (pl. 32) the vein is fairly continuous and has been followed north from its junction with the X vein for about 4,000 feet. As the drifts approach the contact between granodiorite and Calaveras formation, the vein undulates on the strike and splits into many branches, and the gold content is too low to justify stoping. In the lower levels the width of the vein ranges from less than 1 foot to 3 feet or more. The vein walls are generally sharp; gouge of variable width and position is present; and the quartz is commonly sheared or brecciated.

The evidence of postquartz movement is, however, much less clear than on the X vein.

The granodiorite walls are much altered by sericite and ankerite, and both ankerite and calcite occur with the vein quartz. Pyrite, galena, and sphalerite are the principal sulphides.

In the lower levels the stope pattern indicates an unusually irregular distribution of gold, some of which occurs in scattered patches of high-grade ore. Much specimen gold has come from the Pennsylvania mine.

Figure 60 shows the upper workings of the Pennsylvania and adjoining W. Y. O. D. mines, mainly now inaccessible. Their complexity is due to the presence of numerous splits, back-dipping cross-overs, and rolls in the vein. This complexity of the structure is illustrated by the testimony offered in the suits between the Pennsylvania and W. Y. O. D. Cos. The W. Y. O. D., in following a vein to the north, drifted under the Pennsylvania shaft, and eventually the workings of the two companies came together. Because of the irregularity in strike of the Pennsylvania vein, the W. Y. O. D. Co. argued that the apex, claimed by the Pennsylvania Co., did not represent a single vein but was composed of a series of apexes of intersecting veins, some of which, if prolonged, would cross the side lines of the Pennsylvania claim. In support of their contention and as expert witness for the Grass Valley Exploration Co., owner of the W. Y. O. D. mine, Louis Janin [65] advanced the theory "that the country rock was divided into rhombohedral blocks by veins of a subdivisional joint-plane system, and that district veins were formed upon the various faces of the rhombohedron." The court,[66] however, ruled that "the most conclusive fact establishing the continuity of the Pennsylvania vein is this fact—that the vein can be followed as a dominant persistent vein from the surface through continuous stopes down to the lower workings of the mine."

On the 700-foot level, which was accessible in 1931, drifts follow a number of eastward or back-dipping veins, which, from the cross sections offered in evidence in the suit, appear to be cross-over fractures connecting the hanging-wall vein worked by the old Pennsylvania Co. with the footwall vein mined by the W. Y. O. D.

Pennsylvania Hanging Wall vein.—On the 1,700-foot level about 1,000 feet north of the Pennsylvania-X vein junction a weak fracture has been followed into the hanging wall, where it joins the Pennsylvania Hanging Wall vein. This vein is generally weaker than the Pennsylvania and contains little ore. Its continuity to the 1,400-foot level was established by a raise connecting the two levels.

Veins intersected by the 3,400-foot crosscut.—The 3,400-foot level of the Empire mine is connected to the 2,400-foot level of the Pennsylvania mine by a long crosscut extending west from the Empire vein (pl. 36). This crosscut intersects several veins lying between the Empire and Pennsylvania veins and roughly parallel to them, striking north and dipping west, as shown in the section through the crosscut (fig.

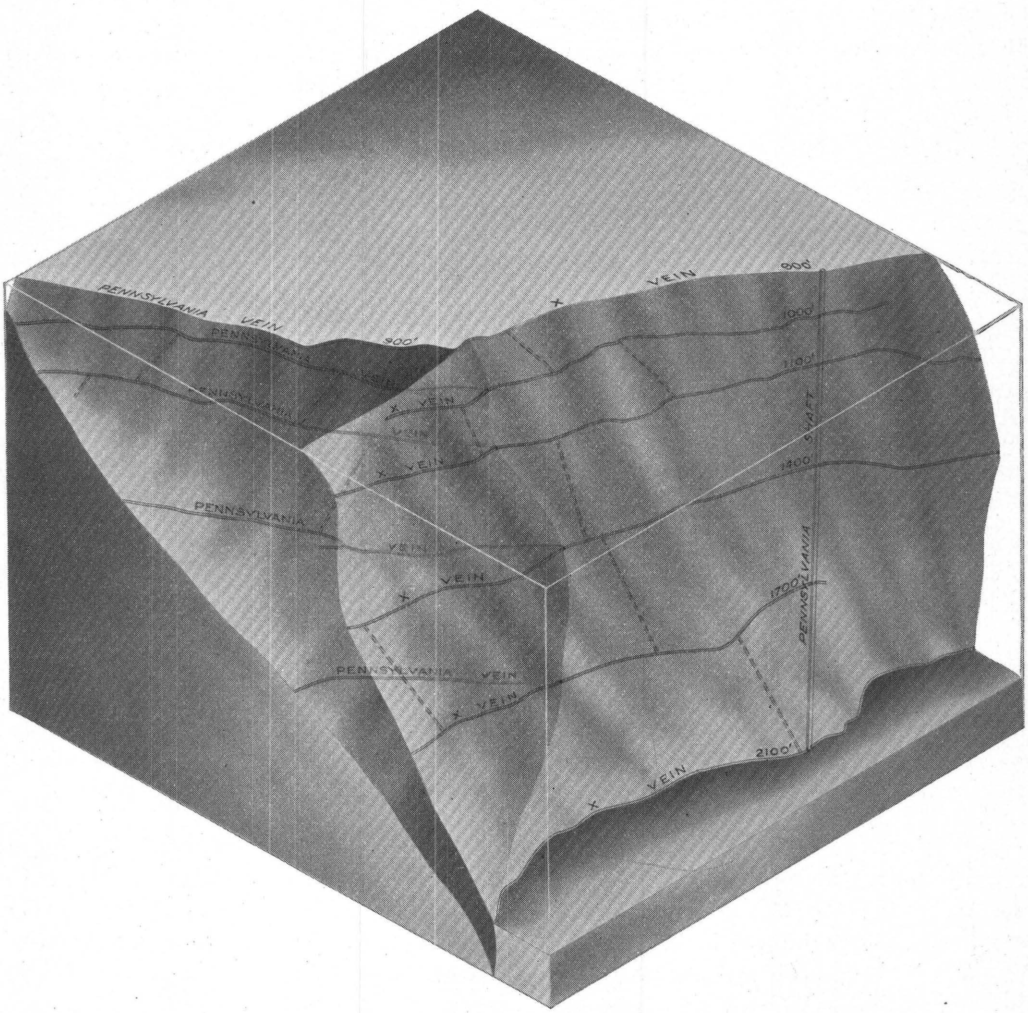


FIGURE 61.—Isometric block diagram showing the junction of the Pennsylvania and X veins between the 900- and 2,100-foot levels of the Pennsylvania mine.

[65] Lindley, C. H., op. cit., vol. 2, p. 1487.
[66] Idem, p. 1488.

62). Drifting has been done on five of these veins without finding ore.

Crossings.—On the 1,400-foot level footwall crosscut are exposed two unusually strong crossings striking N. 24° E. The crossings stand as open fractures 10 to 16 inches between walls. Water flows from both. The 3,400-foot level crosscut from the Empire vein continues westward beyond the Pennsylvania vein. Near the end of the crosscut are several strong crossings. On May 28, 1931, a drill hole in the face, which probably intersected a concealed crossing, was flowing 16 gallons a minute.

figure 60, and the general geologic relations of the veins in the block diagram of the Pennsylvania and X veins (pl. 32).

As shown in the block diagram and on plate 37, the W. Y. O. D. shaft is sunk through a peninsulalike roof pendant of diabase and finally enters the granodiorite between the 1,000- and 1,100-foot levels.

To the north the Telegraph mine is on the same vein, and in 1892 it was followed to an inclined depth of 175 feet.

Comb, massive, and sheared quartz is the principal gangue mineral and is accompanied by minor amounts

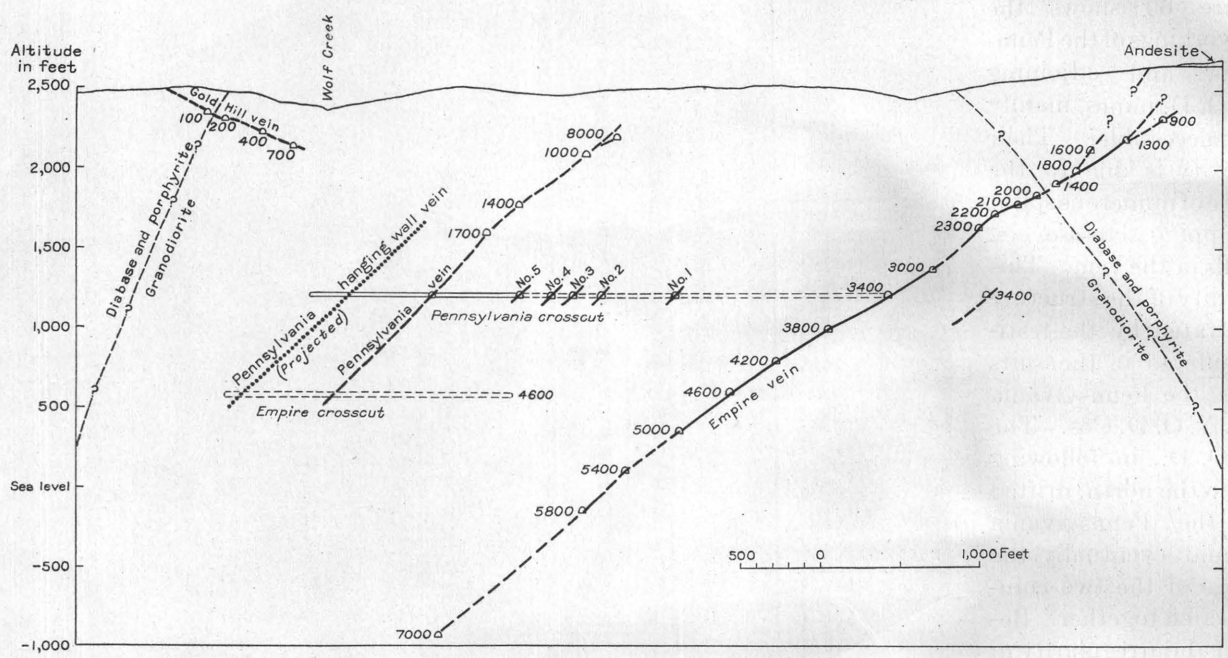


FIGURE 62.—Section through the 3,400-foot crosscut, Pennsylvania mine.

W. Y. O. D. MINE

East and in the footwall of the Pennsylvania vein is the W. Y. O. D. ("Work Your Own Diggings") vein, which strikes to the south and has an average dip of 32° W. The outcrop was only 3 to 6 inches wide, but the vein followed downward widened to 10 inches at 500 feet, 2 feet at 620 feet, and 2½ feet at 70 feet.

The mine was worked superficially until 1888. The production for 1890 was $26,000; for 1891, $53,500; for 1892, $108,700; and for 1893, $143,360. Mr. Fred M. Miller [67] has estimated the total output of the mine to be $1,400,000.

In 1902 the mine passed into the ownership of the Pennsylvania Mining Co. as a result of the lawsuits between the Grass Valley Exploration Co. and the Pennsylvania. A short summary of the litigation is given on page 83. In 1915 the Empire Mining & Investment Co. completed the purchase of the Pennsylvania Co. and the W. Y. O. D. shaft was permitted to cave. The workings are now inaccessible.

Underground workings and stopes are shown in

[67] Oral communication.

of carbonate. Pyrite, galena, sphalerite, and some arsenopyrite are the principal sulphides, making up about 2 percent of the vein material and, according to Lindgren, averaging 2½ to 4½ ounces of gold and 5 to 8 ounces of silver to the ton of concentrate. The ore averaged $20 to $50 a ton.

KATE HAYES VEIN

The Kate Hayes vein, cropping out west of the Pennsylvania vein and roughly parallel to it, was worked in the sixties and is said to have produced $125,000 from ore averaging $35 to $50 a ton. The old shaft, 300 feet deep, was reopened in 1895.

Soon after the Pennsylvania Mining Co. took over the property of the Grass Valley Exploration Co., a raise from the vein on the 1,100-foot level of the Pennsylvania mine was driven to connect with the lower level of the Kate Hayes. The divergence in strike between drifts on the X vein and those on the Kate Hayes detracts from the validity of the otherwise reasonable inference that the Kate Hayes vein is an upward continuation of the X vein. Unfortunately for the solution of the problem, the workings of the Kate Hayes are no longer accessible.

PARR, CASSIDY, AND LINDEN VEINS

The Parr, Cassidy, and Linden veins lie between and parallel to the Pennsylvania and Empire veins. First worked in the sixties, they were explored between 1910 and 1915, when the property was acquired by the Empire Co., and have since been idle. In an area in which change of dip and strike are the rule rather than the exception and breaks in vein continuity are common, correlation of outcrops with veins exposed in deep workings, in the absence of intermediate development, is extremely hazardous. Nevertheless, the discovery on the 3,400-foot level crosscut from the Empire to the Pennsylvania of several intermediate and concordant veins suggests possible correlations with these three veins, whose outcrops occupy similar positions.

EMPIRE MINE

HISTORY AND PRODUCTION

An excellent account of the early history of the Empire mine was given in 1900 by George W. Starr,[68] under whose management the Empire became one of the world's greatest gold mines. Much of the following account is abstracted from his article.

The Ophir vein was found by George Robert in 1850, soon after the initial discovery of gold-bearing quartz on Gold Hill, and in 1854 the Empire Mining Co. was incorporated to work it. The year 1934 marked the eightieth anniversary of the Empire mine—a span of continuous operation. From 1850 to 1928 the value of the ore mined exceeded $30,000,000. Between 1891 and 1928 the yearly average value of the ore ranged between $5.10 and $23.80 a ton, with an average for the period of $11.58.

In the early years the mine prospered, and in 1865–66 a new $200,000 surface plant was installed. The mill was destroyed by fire in 1870, and by 1878, when the mine bottomed at the 1,200-foot level, all the visible ore had been exhausted. Three well-known mining engineers were engaged to examine the property. They reported that the mine was too deep for profitable working and advised that it be closed. Consequently the Ophir shaft was allowed to fill with water, and work was begun on the Rich Hill vein. Later in the year W. H. Bourn, Jr., who had not been wholly convinced of the wisdom of the engineers' report, formed the Original Empire Co. to work on the Ophir vein, and by 1883 the mine was again profitable. In 1886 the number of stamps was increased from 20 to 40. In 1887 Mr. Starr became manager. He resigned in 1893 to go to South Africa but returned in 1898 to find the mine again on the verge of exhaustion. He reassumed management upon the condition that $200,000 be made available for development work, and a program of 600 feet of drifting a month was decided upon. Soon the prospecting program bore fruit and the mine again became productive. Under Mr. Starr's management mining profits accumulated, and the Original Empire Co. became the Empire Mines & Investment Co. Development continued well in advance of mining, the Ophir shaft was deepened to the 4,600-foot level, a winze was sunk on the vein from the 4,600- to the 7,000-foot level, and the Pennsylvania mine was acquired. Again in the 1920's the visible ore reserves dwindled, and in 1928, upon the recommendation of Fred Searls, Jr., the Empire mining properties were acquired by the Newmont Mining Corporation. They have since been worked in conjunction with the North Star as the Empire Star Mines Co. With the change in ownership, Mr. F. W. Nobs became general manager.

Thus, in the last three-quarters of a century, the Empire has twice been on the verge of closing. Both times a vigorous development program has discovered new ore and prosperity has ensued.

[68] Starr, G. W., The Empire mine, past and present: Min. and Sci. Press, vol. 81, pp. 120, 152, 184–185, 1900.

GENERAL GEOLOGIC FEATURES

In the upper part of the mine diabase and porphyrite, with associated pyroclastic breccias, form the wall rock. To the north, in the upper levels, slates of the Calaveras are present, and the 4,200-foot level crosscut enters serpentine. The lower part of the mine is in granodiorite. All the rocks are cut by aplites and basic dikes.

The principal veins are the Empire (Ophir), Rich Hill, and Newmont. Other veins, about which little is yet known, have been cut by workings south of the Empire shaft.

Wall rocks and general structural relations of the Empire mine are shown on the block diagram (pl. 35), and workings north of the shaft, including drifts, crosscuts, and stopes, are shown on plate 36. An east-west section through the shaft is shown in plate 37.

Production of the Empire mine, 1891–1928 [1]

Year	Ore crushed (tons)	Production	Yield per ton (gold at $20.67 an ounce)	Gold per ton (ounces)[2]
1891	17, 318	$96, 980. 80	$5. 60	0. 27
1892	15, 722	80, 182. 20	5. 10	. 24
1893	14, 872	107, 078. 40	7. 20	. 34
1894	16, 925	93, 087. 50	5. 50	. 26
1895	17, 825	92, 690. 00	5. 20	. 25
1896	18, 732	116, 138. 40	6. 20	. 30
1897	15, 104	129, 894. 40	8. 60	. 41
1898	19, 864	343, 647. 20	17. 30	. 83
1899	22, 371	369, 121. 50	16. 50	. 79
1900	11, 570	202, 254. 23	17. 49	. 84

[1] Data from 29th Annual Report of the Empire Mining & Investment Co., and from W. A. Simkins.
[2] Approximate figure derived by dividing yield per ton by 20.67. No allowance is made for silver.

Production of the Empire mine, 1891–1928—Continued

Year	Ore crushed (tons)	Production	Yield per ton (gold at $20.67 an ounce)	Gold per ton (ounces)
1901	30, 260	$720, 214. 73	$23. 80	1. 15
1902	35, 297	616, 948. 67	17. 48	. 84
1903	33, 461	493, 620. 48	14. 75	. 71
1904	34, 100	550, 364. 09	16. 14	. 78
1905	37, 078	553, 583. 49	14. 93	. 72
1906	36, 125	386, 025. 64	10. 69	. 51
1907	31, 100	321, 840. 75	10. 35	. 50
1908	33, 900	478, 451. 48	14. 11	. 68
1909	41, 800	508, 218. 68	12. 16	. 58
1910	43, 200	621, 397. 19	14. 38	. 69
1911	42, 400	613, 865. 91	14. 48	. 70
1912	46, 650	688, 093. 26	14. 75	. 71
1913	78, 852	1, 117, 786. 47	14. 18	. 68
1914	81, 700	1, 088, 250. 23	13. 32	. 64
1915	114, 350	1, 471, 583. 06	12. 87	. 62
1916	138, 928	1, 822, 939. 20	13. 12	. 63
1917	143, 225	1, 848, 623. 62	12. 91	. 62
1918	139, 100	1, 806, 016. 85	12. 98	. 62
1919	137, 843	1, 639, 314. 96	11. 89	. 57
1920	144, 133	1, 697, 929. 47	11. 78	. 57
1921	125, 200	1, 325, 954. 57	10. 59	. 51
1922	143, 200	1, 523, 123. 09	10. 64	. 51
1923	137, 430	1, 260, 089. 21	9. 17	. 44
1924	145, 000	1, 348, 787. 02	9. 30	. 45
1925	135, 000	1, 232, 465. 20	9. 13	. 44
1926	134, 550	1, 217, 140. 34	9. 05	. 43
1927	117, 650	978, 507. 78	8. 32	. 40
1928	90, 100	805, 386. 59	8. 94	. 43
	2, 621, 935	30, 367, 596. 66	11. 58	. 56

Total production of the Empire mine, 1854–1928

Years	Ore crushed (tons)	Yield per ton	Production
1850 to May 1854	(1)	(1)	(1)
1854–63 [2]	28, 100	$37. 59	$1, 056, 234. 40
1865–78 [2]	(?)	(?)	1, 911, 081. 45
1879–90 [3]	59, 508	29. 14	1, 713, 840. 00
1891–1928	2, 621, 935	11. 58	30, 367, 596. 66
			35, 048, 752. 51

[1] Unknown.
[2] MacBoyle, Errol, Mines and mineral resources of Nevada County, pp. 156–157, California State Mining Bureau, 1919.
[3] Derived by subtracting production for 1891–99 from the following totals for the period 1878 to December 1, 1899, as given in the 29th Annual Report of the Empire Mining & Investment Co.: Ore milled, 218,241 tons; value per ton, $14.40; production $3,142,660.40.

EMPIRE (OPHIR) VEIN ZONE

Attitude and dimensions.—The Empire vein zone is a remarkably persistent structural feature. It has been followed down the dip for 7,000 feet and along the strike for over 5,000 feet. Drifts on the deep levels extend from the shaft northward almost under Main Street in the town of Grass Valley.

Although the average strike of the vein zone is about due north, segments strike both northeast and northwest. These irregularities in strike are shown on the development map. The average dip of the vein is 35°, but segments of the vein have both steeper and gentler dips. As shown in the cross section (pl. 37) the Empire shaft follows the Empire vein from the surface to the 1,100-foot level, where the vein splits. The shaft continues down at a lower angle on the hanging-wall vein to the 1,800-foot level, below which the shaft continues in the hanging wall of the Empire vein to the 4,600-foot level, the bottom of the shaft. Approximately 2,500 feet north of the shaft on the 4,600-foot level is the Empire winze, which follows the vein downward on an angle of 40° to the 7,000-foot level.

The Empire fissure is not a simple break that can be followed continuously on the dip and strike; rather it is a zone of variable width and degree of shattering, within which the vein, as defined by the quartz filling, is confined. Thus the vein itself can step from one fracture to another or even from one fracture zone to another, as it does on the major split in the upper levels at the north end of the mine, where the amount of quartz in a hanging-wall zone decreases as that in a footwall zone increases. The complexity of the vein structure is shown on the block diagram.

Wall rocks.—The Empire shaft cuts the diabase-granodiorite contact a little below the 1,100-foot level. North of the shaft, on the 1,100-foot level, apophyses of granodiorite in diabase are cut by the drift. Farther north, the contact, in the plane of the vein, falls a little below the 1,900-foot level and continues at this altitude to the Calaveras contact. South of the shaft the contact plunges sharply and is cut by workings on the 3,000-foot level. The contact is so sharp throughout, that it is usually possible to break a small specimen that shows both rocks in typical facies. In the shaft near the contact the granodiorite contains many dark inclusions (fig. 2). Some of the inclusions are platy, but others are more or less spindle-shaped, their arrangement in the granodiorite is a random one, and the orientation of their axes bears no relation to the plane of the contact.

In the upper levels diabase is somewhat more abundant than porphyrite. The diabase is generally very fine-grained, but its texture may be recognized through a hand lens. All the hornblende is more or less uralitic. The porphyrites have phenocrysts of both augite and plagioclase. In the long footwall crosscut on the 1,100-foot level are exposed pyroclastic breccias containing angular fragments of both diabase and porphyrite.

The granodiorite, which is typical of the district, has been described on pages 12–15.

At the north end of the mine some of the drifts in upper levels enter the Calaveras formation, composed of quartzitic phyllites with a highly altered groundmass of quartz, muscovite, zoisite, and epidote. Coarse quartzitic sandstones contain a similar cement. Bordering the granodiorite in the crosscut at the north end of the 4,200-foot level are zones of highly altered quartzitic sandstone composed of quartz grains cemented by reddish-brown biotite in parallel orientation. These brown contact-metamorphic rocks are readily recognized by their faintly purple cast. Phyllite breccias are exposed in places along the footwall crosscut on the 1,100-foot level.

The extreme north end of the 4,200-foot crosscut enters serpentine, but it was blocked by caving at the serpentine contact.

Aplite dikes on the Empire vein are rare and narrow, but dark dikes are abundant and of varied composition, ranging from quartz-oligoclase-hornblende porphyries to andesine-augite lamprophyres. Mainly, however, the dark dikes are andesites, and commonly they closely resemble the older diabases and porphyrites both in composition and in texture.

All the wall rocks are altered near the veins. Sericite and carbonates have been introduced, and the extent to which they have replaced the original components of wall rocks is more or less dependent upon the distance from the vein fracture, its size, and the amount of vein filling.

Vein fracture.—The Empire vein occupies a strong and persistent fracture, but the width between main walls, the degree of shattering, the abundance of splits and diverging secondary walls, and the amount and distribution of gouge are widely variable.

The main walls of the Empire vein are generally well defined, and the average width between them is between 3 and 6 feet. In some places the fracture narrows to less than 3 feet; elsewhere the distance between walls is as much as 20 feet. Commonly both hanging wall and footwall show strong grooves and ridges. The country rock between the main walls is moderately shattered, and the degree to which it has been replaced by sericite and carbonates appears to be in part dependent upon the degree of shattering. Some gouge is present throughout the fissure zone. It may be confined to one wall or to both walls, or it may cross the vein material from wall to wall. Recurrent movement is recorded by gouge cutting earlier quartz. These gouge seams vary greatly both in width and in the proportion of the interwall space that they occupy. The gouge itself is composed of ground country rock that has been replaced by sericite, carbonates, chlorite, and angular quartz fragments.

Throughout the vein secondary walls diverge from the main walls, usually at low angles. Some of the secondary walls carry quartz and are explored by drifts, but others have only a gouge seam. An increase in the number of diverging walls commonly heralds a vein junction or the passage of the principal quartz seam from one vein fracture to a parallel one in either wall. After long experience the miners acquire a remarkable facility in judging which secondary walls are worth following, and, to a considerable degree, continued mining is dependent upon such judgment. Diverging walls increase in number at the north end of the lower levels, and, like the overlying Pennsylvania, the Empire vein is dissipated in a series of secondary fractures with random strikes.

Vein filling and ore shoots.—Quartz is the principal vein mineral. In some places it fills the vein fracture from wall to wall, attaining a thickness of 6 to 9 feet; elsewhere it forms sheeted zones cementing fractured country rock between the main walls. All textural types are present. Comb quartz occurs on the 7,000-foot level, the bottom of the mine, and both comb quartz and massive milky quartz occur at higher levels. Sheared and ribbon quartz are the most abundant types, but coarse angular quartz breccias cemented by later quartz (pl. 8, *F*) have been seen on many levels. Commonly three or four generations of vein filling can be identified by their intersection relations and associated gouge. As on other veins in the district, the Empire vein filling unmistakably points to recurrent quartz deposition alternating with vein movement.

Both calcite and ankerite are widely distributed. They appear to be later than the greater part of the quartz, and the calcite is generally younger than the ankerite. They are as abundant on the lower as on the upper levels.

Pyrite is the principal vein sulphide; galena and sphalerite occur in lesser amounts. Arsenopyrite is much less common, and molybdenite and scheelite are very rare. On the average, between 1 and 4 percent of the vein material consists of sulphides.

Gold occurs both in the quartz and in the sulphides. It is more often found in sheared and ribbon quartz than in the comb and massive types. In the sulphides it fills minute cracks in the older fractured pyrite and appears to be contemporaneous with galena. The average gold content of the sulphides ranges from 2½ to 10 ounces to the ton. The gold is recovered by cyanidation. The average gold content of the ore for the period 1891–1928 was 0.56 ounce to the ton. In the past many pockets of high-grade ore have been found, but in later years most of the "specimen ore" of the Empire mine has come from the Pennsylvania vein. Ore shoots, as outlined by stoped areas, are shown in plate 36.

Crossings.—Vertical or nearly vertical joints striking northeast are abundant throughout the mine. They occur both singly and in zones. Most commonly these "crossings" are closed and show no evidence of displacement. Less commonly they are open, permitting the descent of mine water. More rarely crossings are offset by the vein fracture, or the vein fracture is offset by the crossings. As in other veins of the district, sharp changes in width of quartz and in gold content take place on crossings.

The remarkable quartz-filled crossing exposed in the upper workings of the No. 2 vein, North Star mine, was intersected by the 4,600-foot crosscut from the Empire shaft station to the X vein, and a short drift was run on it. The crossing is vertical and has an average width of 2 feet. Barren pyrite, galena, and sphalerite occur in the quartz.

OTHER VEINS IN THE EMPIRE MINE

Since 1931, when the accompanying maps and block diagram of the Empire mine was completed, exploratory development work has disclosed several new veins.

Wentworth vein.—The Wentworth vein lies 500 feet east and in the footwall of the Empire vein, which it parallels in both dip and strike. It is intersected by a crosscut driven eastward from a point on the 4,200-foot level Empire drift about 800 feet north of the Empire shaft. From this crosscut about 2,000 feet of drifting has been done on the Wentworth vein. Quartz showing all the common textures of the district and varying in width from 2 to 20 inches is exposed in the drift. The vein was also found on the 4,600-foot level, north of the Empire shaft.

Newmont vein.—Up to 1928, when the Newmont Mining Co. acquired the Empire mine, little exploration on deep levels south of the Empire shaft had been done. Since 1928, however, workings on the 2,000-, 2,700-, 3,000-, 3,800-, and 4,200-foot levels have been extended southward, and several veins have been found.

More development work has been done on the Newmont vein than on any other south of the shaft. This vein strikes N. 10° E. and dips southeast. Although its dip is conjugate to that of the Empire vein, the Newmont vein has not been traced north of the shaft, where the Empire is strong, nor has the intersection of the two veins been found south of the shaft.

Drifts on the Newmont vein have been driven on the 2,700-, 3,000-, 3,800-, and 4,200-foot levels. Raises from the 4,200- to the 3,800-foot and from the 3,000- to the 2,700-foot have established its continuity between those levels.

The vein is similar in structure and mineral composition to others in the district. The vein fracture is complex, with many changes in dip and strike. At the north ends of the drifts the principal vein fracture appears to be dissipated in numerous diverging walls as the Empire shaft is approached. Though the quartz shows all the common textures, massive milky quartz and ribboned quartz are most common. Ankerite is an abundant gangue mineral, and in many places it cements brecciated quartz (pl. 20, *A*). Pyrite is the principal sulphide, and galena and sphalerite occur less abundantly. Rarely a late pyrite that carries no gold fills cracks in vein quartz (fig. 29). The vein ranges in width between a narrow seam and 3 feet.

3,000 South vein.—On the extreme south end of the 3,000-foot level (pl. 35) a vein that strikes N. 15° W. and dips northeast has been followed for about 2,000 feet, and a little ore has been mined. The vein has a narrow but persistent gouge, and the quartz attains a maximum thickness of 5 feet. The footwall in a pillar in one of the stopes showed 2 inches of older quartz rich in sulphides. This was cut by 6 inches of younger sulphide-free quartz, and all the quartz was cut by carbonate veinlets. It is probable that a vein lying in the footwall of the Newmont on the 2,700-foot level is the same as the 3,000 South vein. Although its continuity is not established, a long-range downward projection of the New York Hill vein of the North Star mine comes very close to the position occupied by the 3,000 South vein of the Empire mine and suggests the possible identity of the two veins.

Further development work in the area south of the shaft will make possible the correlation of several other new veins that have been located but not yet explored.

RICH HILL MINE

South of the Empire shaft, to the west and in the hanging wall of the Empire vein, is the Rich Hill vein, which strikes a little west of north and dips 35° SW. The Rich Hill shaft (fig. 63) follows the vein to the 2,100-foot level at a vertical depth of 1,000 feet beneath the surface, a distance on the incline of about 1,800 feet. In the early days the Rich Hill vein was worked from the Empire shaft, and in 1930 drifts on the Rich Hill were still accessible from 800- and 1,100-foot levels of the Empire mine. Caving on both levels, however, prevented access to the Rich Hill shaft. The geology of this vein shown on the block diagram (pl. 35) was taken from a generalized map in the files of the Empire mine.

Like most of the westward-dipping veins of the Empire-Osborne Hill group, the vein is fairly persistent in strike despite many abrupt changes in individual vein segments. Splits were followed by drifts on many of the levels. On the 2,100-foot level a crosscut was driven 1,900 feet east into the footwall. It cut several northward-striking tight quartz seams, but apparently none were sufficiently promising to warrant more than a few feet of drifting.

The average thickness of the quartz on the levels accessible in 1930 was mostly less than 1 foot. Comb, massive, and sheared quartz were present and were accompanied by pyrite and galena with lesser amounts of sphalerite and arsenopyrite.

As the Rich Hill mine was worked by the Empire Co., separate production figures were not obtainable.

MINES SOUTH OF RICH HILL

All the mines of the Pennsylvania-Empire-Osborne Hill systems south of the Rich Hill were inaccessible during the field seasons spent in the district. Most of the available information about them has been incorporated in plate 38, which shows the underground workings of the Daisy Hill, Orleans, Houston Hill, Prescott Hill, Betsy, Sultana, Osborne Hill, Centennial, and Conlin mines.

The veins are all members of a complex system striking northwest and dipping southwest. All are enclosed in diabase and approach the granodiorite contact in depth.

Most of the veins were worked before 1880. In 1903 the Orleans, Prescott Hill, Sultana (Electric), Houston Hill, and Centennial were consolidated as the

Sultana Gold Mining Co. Between 1903 and 1916 over 12,000 feet of drifting and 3,000 feet of crosscutting was done in the Sultana properties, developing ore which yielded $750,000.[69] Shortly thereafter the mines were closed.

Fred M. Miller [70] has estimated the total production of the Orleans-Sultana-Osborne group of veins to be $7,500,000.

Orleans shaft was unwatered in 1916, but the mine has not been worked in recent years. The vein fracture is reported to average 2 feet in width and the quartz to average 8 inches. Sulphides, mainly pyrite, make up 3 percent of the ore and are reported to average 3.5 ounces of gold and less than 1 ounce of silver to the ton. As shown in the mine map (pl. 38), most of the stopes are above the 400-foot level.

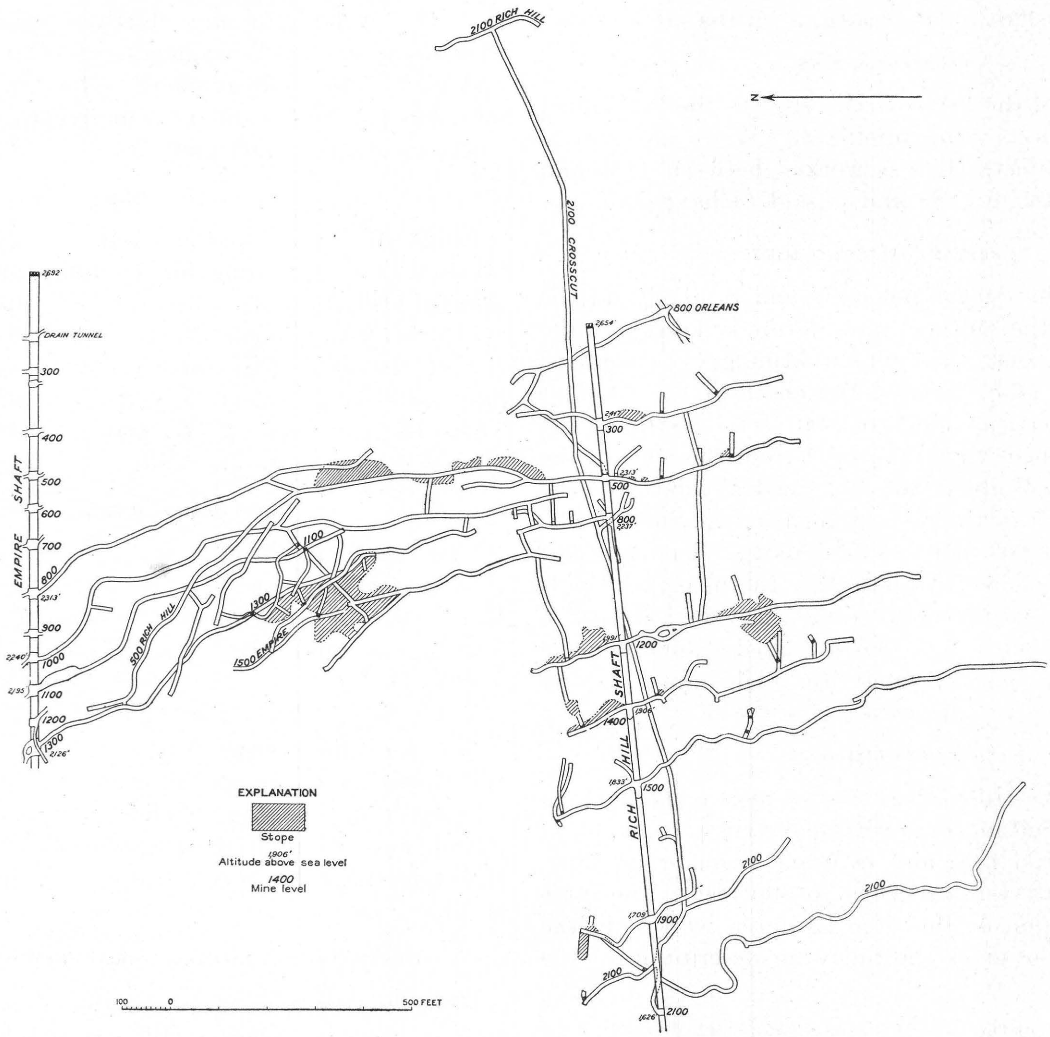


FIGURE 63.—Development map of the Rich Hill mine, showing workings connecting with the Empire mine.

DAISY HILL MINE

The Daisy Hill mine is about 2,500 feet south of the Rich Hill shaft and is probably on the same vein. It has been idle for many years. The mine workings are shown in plate 38.

ORLEANS MINE

The Orleans vein lies in the footwall of the Rich Hill vein and is probably a southward continuation of the Ophir vein. It strikes N. 30° W. and dips on an average of 40° SW. The vein has been followed by an inclined shaft that reached a depth of 500 feet vertically beneath the surface. A crosscut on the 800-foot level connects with the Rich Hill mine. The

[69] MacBoyle, Errol, op. cit., p. 251.

[70] Blueprint map of Grass Valley, Nevada City, and Rough and Ready mining districts, Grass Valley, 1933.

HOUSTON HILL MINE

East and in the footwall of the Orleans is the Houston Hill vein. It was mined between 1861 and 1870 through an inclined shaft that reached a vertical depth of 175 feet. The vein is reported to be narrow but rich. Bean's Directory credits the mine with a production of $500,000 between June 1864 and April 1867. A footwall crosscut on the 700-foot level of the Orleans mine intersected the Houston Hill vein, and a raise was driven to connect with the old workings. Developments on the vein are shown in plate 38.

PRESCOTT HILL AND BETSY MINES

The Prescott Hill vein strikes northwest and dips 25° SW. In the early sixties a shaft had been sunk 300 feet on the incline. In 1906 the Sultana Co. reopened the mine and resumed sinking, reaching an inclined depth of 1,700 feet in 1909, but little ore was found below the 750-foot level. Footwall crosscuts were run on the 750- and 1,750-foot levels. When the Sultana Co. suspended operations the Prescott Hill shaft was abandoned, and in 1931 the collar was badly caved. Late in 1934 the Empire Co., which had meanwhile acquired the Sultana Mining Co.'s properties, reopened the shaft.

The Betsy shaft, to the south, is on the same vein.

SEBASTOPOL MINE

Southeast of the Prescott Hill shaft is the Sebastopol shaft, following a vein dipping 35° W. to an inclined depth of 180 feet. It was worked between 1856 and 1858 and again in 1880 and is said to have produced $200,000.

SULTANA (ELECTRIC) MINE

South of the Sebastopol mine and probably on the same vein is the Sultana mine, formerly known as the Electric. In 1903 the Sultana Mining Co., acquired the property and extended the shaft to the 800-foot level, at a vertical depth of 300 feet. South of the shaft an inclined winze was sunk from the 800- to the 1,600-foot level, about 860 feet vertically beneath the surface. Most of the ore obtained by the Sultana Co. came from the 800-foot level and above. Underground workings are shown in plate 38. In the upper levels the wall rock is diabase breccia, the vein averaged 1 to 2 feet in width, and the principal sulphides were pyrite, galena, and arsenopyrite. The mine has not been worked in recent years.

OSBORNE HILL MINE

The Osborne Hill vein is west of and in the hanging wall of the Sultana or Sebastopol vein. It was first worked between 1852 and 1870 and reopened in 1899, when the shaft was deepened to 600 feet. The mine was in operation at the time Lindgren worked in the district, and he gives the following description of the geology: [71]

> The character of the wall rock varies somewhat: It is in part a very fine-grained uralite diabase, in part a hornblende porphyrite or a breccia of porphyrite and brownish argillite or fine-grained sandstone.
>
> The vein strikes north-northwest with many local curves and irregularities, and the dip varies from 29° in the upper levels to 44° in depth. In some parts, as on the fifth level north, the vein runs down to a seam, which, though containing rich ore, is too small to work. The main ore body was exposed on the fifth level north, which shows excellent ore 3 to 4 feet wide said to average 1½ to 2 ounces per ton. * * * The vein makes less the impression of a continuous open space filled with quartz than of a zone of crushed rock subsequently filled with quartz. Comb structure and vugs filled with crystals are very abundant. Banded structure by deposition and ribbon structure by subsequent sheeting both occur. * * * The ore contains arsenopyrite with some pyrite and a little zinc blende, galena, and occasional chalcopyrite, in all 1¾ percent sulphurets. * * * The gold is 767 fine; the sulphurets contain very little silver. * * * A branch vein with a steep dip, called the Shoofly, lies to the west of the Osborne Hill vein.

[71] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 255.

The mine workings are shown on plate 38.

CENTENNIAL MINE

South of the Osborne Hill mine and probably on the same vein is the Centennial mine, said to have produced $600,000 between 1876 and 1883. The vein dips 30° W. The wall rocks are chiefly "porphyrite-breccia with many brownish fragments of sedimentary flinty rocks." [72] The vein averaged 1 foot in width. The mine has not been worked for many years. The mine workings are shown on plate 38.

CONLIN MINE

Lindgren mapped a strong vein striking a little west of north and extending for 1¼ miles along the west slope of Osborne Hill, called the Lafayette and Comet vein, after two tunnels which cut it. Near the north end of the outcrop is the Conlin mine, whose shaft has followed the vein to a vertical depth of 200 feet. There the vein dips 42° W. and is 2 feet wide. Porphyrite breccia forms the walls.

BEN FRANKLIN MINE

The Ben Franklin mine is on a northward-striking, westward-dipping vein on the west slope of Osborne Hill at the diabase-granodiorite contact. It has been worked intermittently for many years, the last time in 1924.

OTHER VEINS OF THE SYSTEM

Between the collars of the Sultana and Osborne Hill shafts are four veins, all dipping west. From east to west they are the Sanders, Payday, Kings Hill (which may be a southern extension of the Prescott Hill vein), and Phoenix. Little work has been done on them.

DIAMOND-BULLION-ALASKA VEIN SYSTEM

Close to the granodiorite-diabase contact on the western foot of Osborne Hill are the Big Diamond, Bullion, and Alaska veins, striking northwest and dipping east, conjugate to the Empire-Osborne Hill vein system. As the outcrops of the three veins are roughly in line with one another it is probable that they are segments of a single continuous vein. Fred M. Miller [73] has estimated the production of the group as $3,500,000, which may be somewhat high.

More mining has been done on the Galena-Bullion vein than on any others of this group. The Bullion mine was first worked in the sixties and again in the early part of this century, closing in 1906. In 1933 the Consolidated Bullion, Inc., reopened the mine, and in August 1934 my request to study the mine was denied.

[72] Idem, p. 256.

[73] Op. cit.

Northwest along the projected strike of the Bullion is the Big Diamond vein, which produced a considerable amount of ore between 1869 and 1872. Crossing the Big Diamond is the Little Diamond vein, which strikes east and dips 48° S.

Southwest of the Bullion is the Alaska shaft, on what is probably the same vein. It was last worked in 1916 and has since been idle.

MINES IN THE SERPENTINE AREA

As the Spring Hill and Idaho-Maryland were the only mines in the serpentine area that were active during the seasons spent in the field and as permission to study the underground geology of the Idaho-Maryland mine was denied, the following brief mine descriptions are necessarily based upon the reports of Lindgren and MacBoyle and upon such mine maps as could be obtained.

ST. JOHN MINE [74]

The St. John mine is due north of Grass Valley, near the northern edge of the quadrangle. It has been idle since 1894. A steeply inclined shaft 500 feet deep encountered a blind quartz vein with a maximum observed width of 10 feet on what appears to be a faulted contact between porphyrite on the hanging wall and slate of the Calaveras formation on the footwall. A crosscut in the hanging wall through interfingered serpentine and porphyrite cut several quartz stringers carrying gold.

COE MINE [75]

A strong quartz vein striking N. 80° W. and dipping 60° NE. crops out west of the Grass Valley and Nevada City highway. It can be traced for several hundred feet to the northwest. This ledge, which is 6 feet thick in places, is possibly the best-exposed outcrop of a vein that can be found in the district today.

The vein was worked in the early days through a shaft 550 feet deep and is reported to have produced $500,000. It was reopened in 1900, the shaft was deepened to 1,150 feet, and considerable drifting was done. The mine was closed in 1904 and has since been idle.

The mine dump contained serpentine, slate, gabbro, an unusually coarse and felty diabase, and a hornblende lamprophyre. Much of the quartz on the dump showed comb structure.

CROWN POINT MINE [76]

The Crown Point vein is south of Wolf Creek, on the eastern outskirts of Grass Valley. It strikes northwest and dips 70° to 80° NE. The vein is unique in the district because of the pyrrhotite which it contains. In 1931 the dump yielded serpentine, micaceous phyllite, and quartz containing pyrrhotite.

[74] Lindgren, Waldemar, op. cit. (17th Ann. Rept.), p. 223.
[75] Idem, p. 222. MacBoyle, Errol, op. cit., p. 144.
[76] Lindgren, Waldemar, op. cit., pp. 231-232. MacBoyle, Errol, op. cit., p. 149.

The Crown Point vein is cut by the north end of the 4,200-foot crosscut of the Empire mine (pl. 35). There a fracture zone dipping 75° NE. contains stringers of quartz with pyrrhotite and pyrite and large amounts of later carbonates. Wall rocks of both diabase and slate of the Calaveras formation are impregnated with magnetite. The fracture zone is 20 feet wide, but the maximum observed width of quartz-pyrrhotite vein material was 2 feet. According to Mr. F. W. Nobs,[77] assays of composite samples taken across the whole disturbed zone showed little gold, and the maximum assay for the quartz-pyrrhotite vein was $2 a ton.

SPRING HILL MINE

The Spring Hill mine is in the northeastern quadrant of the quadrangle, about 2,000 feet northwest of the shaft of the Idaho-Maryland mine. The Spring Hill vein strikes east and dips south. In the early days of mining at Grass Valley a shallow shaft was sunk on the vein. In 1931 the mine was reopened under the management of H. R. Plate. The old inclined shaft was deepened to a vertical depth of 530 feet, and drifts on the 500- and 900-foot levels were driven. Mr. H. F. Lynn, the company geologist, accompanied me underground, and I am indebted to him for his detailed mapping of the diabase-serpentine contacts on the Spring Hill property, which have been incorporated in the geologic map of the quadrangle. Most of the development work has been done on the Spring Hill vein, which proved to be disappointing.

The rocks exposed underground are serpentine, diabase, and a small amount of diorite. Serpentine is most abundant. It is variable in texture and in the amount of talc that has been developed from it. Usually it forms poor walls, expanding and crumbling upon exposure to the circulating air in the drifts and requiring timbering. The dark-green dense serpentine breaks along innumerable small slickensided planes which cut it. Adjoining the veins much carbonate has been introduced into the serpentine.

The diabase is generally somewhat coarser than that characteristic of the southern half of the quadrangle. Much of the hornblende is uralitized, and some chlorite is developed. The plagioclase contains sericite and carbonates, and some albite has been introduced. One specimen of coarse diabase from the dump approaches a hornblendite in composition. Porphyrite is present but less plentiful than diabase. Like the serpentine, the greenstones are highly carbonatized along the veins. On the east end of the 900-foot level a small amount of diorite is exposed.

In the greater part of the workings the hanging wall and foot wall are not the same rock. Where one is serpentine the other is diabase. Because of this mismatching of wall rocks and the apparent intrusive character of the diabase, Lynn [78] has advanced the

[77] Oral communication.
[78] Lynn, H. F., oral communication, August 1934.

idea that stocks of diabase have been faulted along the vein fracture with sufficient displacements to overlap dissimilar rocks. This interpretation necessitates a displacement on the vein of several hundred feet.

EUREKA-IDAHO-MARYLAND VEIN

EUREKA MINE

The Eureka-Idaho-Maryland vein was discovered in 1851, and in 1864 a vertical shaft 100 feet deep found the great Eureka-Idaho ore shoot (fig. 64). The mine was actively worked until 1873. In 1877, when the ore shoot had been mined to the property line of the adjacent Idaho claim, the mine was closed. Workings had reached a depth of 1,200 feet, but no good ore was found below 600 feet. The Eureka mine is credited with a total production of $5,700,000.[79]

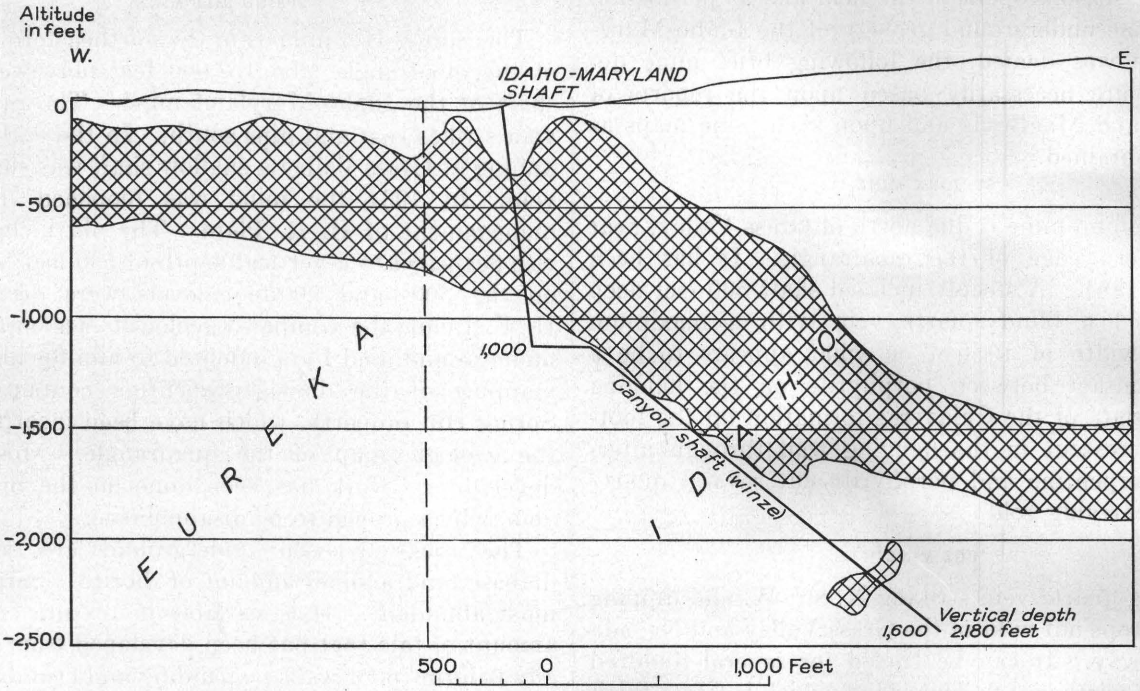


FIGURE 64.—Approximate outline of the Eureka-Idaho ore shoot. (After Lindgren.)

IDAHO-MARYLAND MINE

History and production.—The Idaho mine was located in 1865, and in 1867, at a depth of 300 feet, the eastward continuation of the Eureka ore shoot was found. Since 1867 the mine has been operated by five companies and has prospered under the first and last, or present company. The brief historical and geologic sketch here given is compiled from reports by Lindgren,[80] MacBoyle [81] (the present operator), and Logan.[82] No information about the geology of the present workings was obtained.

The first period of mining extended from 1867, when the Idaho Quartz Mining Co., with Edward Coleman as president was organized, until January 1893. During this time over $11,000,000 in gold was produced and $5,000,000 paid in dividends. The ore came from the Eureka-Idaho shoot (fig. 64), which averaged 2½ feet in width and yielded 1 ounce to the ton in gold. The shoot was worked through a shaft inclined at an angle of 70°, which extended to the 1,000-foot level and an inclined winze raking to the east, called the Canyon shaft, that bottomed on the 1,600-foot level, at a vertical depth of 2,180 feet. In 1893, in consequence of a lawsuit between the Idaho and Maryland Cos. over the eastward continuation of the Eureka-Idaho shoot, the Maryland Co. acquired the Idaho Quartz Mining Co. upon payment of $85,000.

The second period was that of operation by the Maryland Co. under management of S. P. Dorsey, extending from February 1893 until 1901, during which $1,250,000 in gold was produced. A winze was sunk from the 1,600- to the 1,900-foot level, but in 1894 a fire destroyed the hoist and the mine was flooded and workings below the 1,600-foot level were not reclaimed. In 1901, partly because of the bad condition of the workings, the mine was closed.

It remained idle until 1903, when it was bonded to the Idaho-Maryland Development Co., which worked it until 1914. This company succeeded only in reopening it to the 1,000-foot level, and the $300,000 in gold it produced came mainly from old stopes and pillars left behind by the earlier operators.

The fourth period extended from 1918 to 1925, when the mine was operated by the Metals Exploration Co., financed by H. P. Whitney. At a cost greatly exceeding the $500,000 in gold that was produced, the main shaft was extended downward 1,000 feet to the 2,100-

[79] Lindgren, Waldemar, op. cit., p. 224.

[80] Lindgren, Waldemar, op. cit., pp. 224–229.

[81] MacBoyle, Errol, Mines and mineral resources of Nevada County, pp. 185–191, California State Mining Bureau, 1919.

[82] Logan, C. A., Nevada County: California Dept. Nat. Resources, Div. Mines, State Mineralogist Rept., vol. 26, pp. 115–118, 1930.

foot level at a vertical depth of 2,000 feet, drifts on the 2,000- and 2,100-foot levels were driven from the main shaft and other drifts from the Dorsey winze, and a new winze was sunk 850 feet below the 2,000-foot level. Failing to find a new ore shoot, the company suspended work in 1925.

Work was shortly thereafter resumed by the Idaho-Maryland Mines Co., under the management of Errol MacBoyle. New ore was found, and, for the first time in the present century, the mine entered a period of prosperity. Production for the years 1930, 1931, and 1933, quoted from Mineral Resources and the Minerals Yearbook, is shown in the following table:

Production of the Idaho Quartz Mining Co., 1868–1903

[After MacBoyle]

Year	Ore mined (tons)	Production	Dividends
1868	763	$45, 534	----------
1869	9, 489	308, 208	$170, 500
1870	9, 782	189, 963	37, 200
1871	11, 133	395, 355	232, 500
1872	----------	400, 465	162, 750
1873	28, 825	1, 024, 591	682, 000
1874	28, 401	664, 811	317, 750
1875	28, 103	495, 569	172, 050
1876	29, 720	562, 274	255, 750
1877	29, 250	530, 143	240, 250
1878	33, 833	596, 850	263, 500
1879	32, 370	499, 379	168, 950
1880	11, 611	226, 078	127, 100
1881	27, 540	642, 538	271, 250
1882	27, 540	568, 572	263, 500
1883	28, 572	364, 599	[1] 34, 500
1884	31, 143	561, 895	271, 250
1885	30, 518	370, 197	99, 200
1886	29, 244	547, 569	263, 500
1887	26, 686	492, 638	235, 600
1888	26, 664	603, 694	325, 500
1889	21, 448	407, 385	178, 250
1890	20, 321	268, 904	52, 700
1891	16, 759	314, 037	10, 250
1892	16, 500	248, 270	57, 450
1893 [2]	----------	40, 904	[3] 23, 783
	567, 029	11, 470, 573	5, 008, 433

[1] New equipment.
[2] January only.
[3] Balance on hand.

Average value per ton, $20.23.

Production of Idaho mine under ownership of the Maryland Co. and management of S. P. Dorsey, 1893–1901

[After MacBoyle]

Year:	*Production*
1893 [1]	$258, 220
1894	193, 182
1895	247, 600
1896	197, 239
1897	147, 646
1898	93, 242
1899	68, 344
1900	31, 503
1901	9, 040
	1, 246, 020

[1] 11 months, February to December.

Total production of the Idaho-Maryland mine, 1868–1932

Period	Operating company	Production
1868–1893	Idaho Quartz Mining Co	[1] $11, 470, 573
1893–1901	Maryland Co	[1] 1, 246, 020
1904–1914	Idaho-Maryland Development Co	[1] 311, 613
1919–1925	Metals Exploration Co	[2] 560, 000
1926–1932	Idaho-Maryland Mines Co	[3] 2, 350, 000
		15, 938, 206

[1] MacBoyle, Errol, op. cit., pp. 187–188.
[2] Logan, C. A., op. cit., p. 115.
[3] Estimated from published figures for parts of the period.

Production of the Idaho-Maryland mine, 1930, 1931, and 1933

Year	Ore mined (tons)	Production	Value per ton (gold at $20.67+ an ounce)	Gold (ounce per ton)
1930	19, 452	$241, 059	$12. 40	0. 60
1931	40, 005	574, 573	12. 77	. 61
1933	68, 233	866, 245	12. 69	. 61

Geology.—The Eureka-Idaho-Maryland vein strikes N. 77° W. and has an average dip of 70° SW., ranging between 50° and 80°. It was marked by strong surface croppings on the western or Eureka end, but it could not be followed on the surface east of the present Idaho-Maryland shaft. As shown in Lindgren's section through the Maryland shaft (fig. 65), the hanging wall is composed of diabase and gabbro, and the footwall is serpentine. All the rocks are highly altered and contain much ankerite. Mariposite commonly occurs in the serpentine.

The famous Eureka-Idaho ore shoot (fig. 64) had a pitch length of almost 1 mile and a breadth of 500 to 1,000 feet. The width of the vein within the ore shoot averaged 2½ feet, but in places it was as much as 8 feet. The average gold content of the ore has been estimated at 1 ounce to the ton. Between 1 and 2 percent of the ore was composed of sulphides, of which pyrite was most abundant. Lesser amounts of galena, chalcopyrite, and sphalerite were present. The sulphides yielded between 5 and 20 ounces to the ton in gold. Most of the gold, however, was free, and much specimen ore has come from this famous ore shoot.

There is little available geologic information about the present workings which are to the east of the Canyon shaft. In 1933 ore 16 feet wide was reported on the 1,200-foot level,[83] and the increasing production is witness to successful development work.

It is to be hoped that the geologic staff of the company will be permitted to publish the results of their studies pursued actively since 1931, for the Idaho-Maryland mine holds the key to the complex geology of the serpentine belt. The extent of faulting on the

[83] Eng. and Min. Jour., vol. 134, p. 86, 1933.

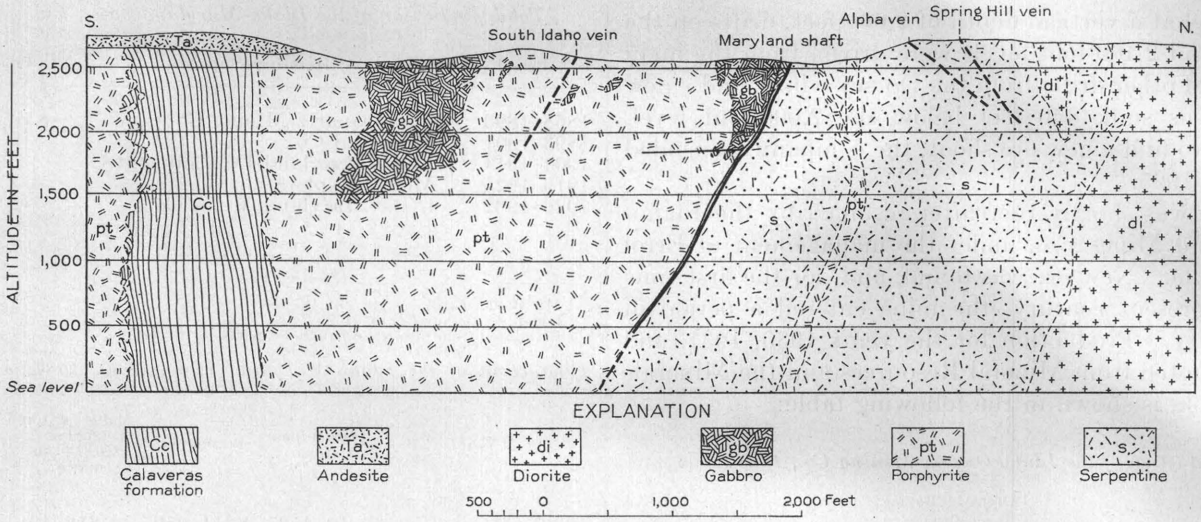


FIGURE 65.—Section through the Maryland shaft, 1894. (After Lindgren.)

Idaho-Maryland vein, the age relations of the serpentine and granodiorite vein fractures, the succession

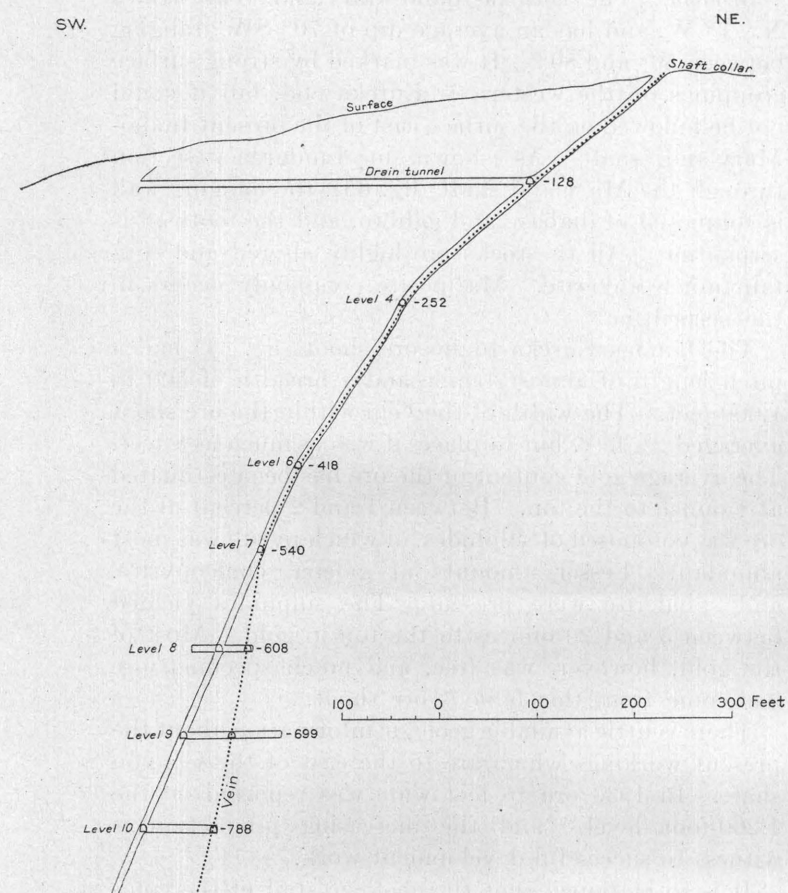


FIGURE 66.—Generalized section through the inclined shaft of the Brunswick mine. Based upon a mine map by E. C. Uren.

of the serpentine-gabbro-diorite instrusions, and the distribution and age relations of the reported tellurides are a few of the general problems whose solution lies in that mine.

BRUNSWICK MINE

The Brunswick is southeast of the Idaho-Maryland, in the area of amphibolite schist. It was located early, but by 1888 it was only 300 feet deep. When Lindgren studied the mine in 1894 an inclined shaft following the vein bottomed at 700 feet. The inclined shaft was later extended to the 1,250-foot level, and in 1915 a vertical shaft about 3,000 feet southeast of the old inclined shaft was put into service. In 1918 shaft sinking stopped at a depth of 1,347 feet. The 1,250-foot level of the old shaft connects with the 900-foot level of the vertical shaft. The mine was profitably operated for a few years before the World War, but in 1917 the scarcity of labor slowed up development work, and in 1918, because of high labor costs and depleted ore reserves, work was suspended for the duration of the war.[84] The mine was unwatered in 1922 and was operated in 1923, 1925, and 1926. In 1927 it was again closed. In 1933 the Idaho-Maryland Co., which had meanwhile acquired control, began pumping preparatory to putting it in production. The mine workings in 1924 are shown in plate 39.

The Brunswick vein belongs to the Idaho-Maryland vein group. It strikes N. 50° W. and dips southwest. As shown in figure 66, the dip steepens from 45° at the surface to 70° below level 7. As the mine was not accessible in 1930 and 1931, the following geologic notes are taken from Lindgren's and MacBoyle's reports. In describing the character of the Brunswick vein on level 7 of the inclined shaft, Lindgren[85] says:

> The vein is contained in a chloritic schist derived by dynamometamorphic processes from a porphyrite breccia and intersects the strike of the schist at an acute angle. There are usually two well-defined walls, 2 to 4 feet apart. The space between the walls is only locally wholly filled with massive milky quartz, being generally occupied by soft chloritic schists, extensively altered by hydrothermal processes; the schists are either parallel to the walls or, as is frequently the case, broken and irregular; they contain streaks and ramified veins of massive quartz (fig.

[84] Logan, C. A., Additional notes in MacBoyle's 1919 report, op. cit., p. 127.
[85] Lindgren, Waldemar, op. cit., p. 230.

67), which sometimes increases in thickness and occupies the whole space between the walls. East of the shaft (on the No. 7 level) the vein closes down to a mere seam. Free gold is rarely visible in the quartz, and the sulphurets, which generally are rich, consist of pyrite, chalcopyrite, and galena.

The stoped areas are shown on the mine map (pl. 39). The largest ore shoot occurs in the eastern half of the

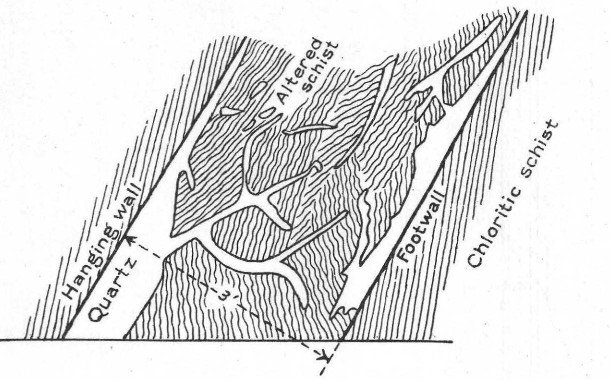


FIGURE 67.—Sketch section of the Brunswick vein on the 700-foot level. (After Lindgren.)

vein, where it has been mined from the 400- to the 1,200-foot level, through a vertical range of about 600 feet. Ore from this shoot is said to have averaged 1 ounce to the ton in gold. There are several vein splits in which stopes have been opened on both foot wall and hanging wall. From the semicircular trend of the drift on the 400-foot level and the converging raises above that level, as shown on mine maps, it appears that the vein flattens and reverses its dip, forming a domelike structure whose axis plunges to the southeast. Similar structures occur on the New Rocky Bar, Pennsylvania, and New York Hill veins.

In 1917 ores from the upper levels at the south end of the vein contained 1.6 percent of sulphides, averaging 1.64 ounces of gold to the ton, and ore from the lower levels contained 2.0 percent of sulphides, averaging 2.80 ounces of gold to the ton.[86] The sulphide content of the veins is much lower than the average for the district.

UNION HILL MINE

The Union Hill vein, on the north bank of South Wolf Creek south of the Brunswick inclined shaft, was worked in 1854, and the ore reduced in an arrastre. Between 1865 and 1870, when it bottomed at the third level, the mine was profitable and is reported to have yielded $250,000 up to that time. At the beginning of this century the mine was reopened, and a new shaft, beginning in the footwall of the Union Hill vein on the 300-foot level, was sunk to a depth of 600 feet. Mining was continued with occasional interruptions until 1911, when operations were suspended. In 1914 the mine was again opened and mining continued until 1918. In 1930–31 the property was idle and inaccessible. At the present time it is controlled by the Idaho-Maryland Mines Co.

The mine lies in the area of amphibolite schist, described by Lindgren as a schistose porphyritic breccia.

The mine map (fig. 68) shows workings on several veins. Figure 69 is a generalized section through the Union Hill shaft. As it was constructed from a mine map and oral reports, the projection of the veins is largely hypothetical, but because even a rough and inexact sketch conveys a clearer structural concept than written description alone, it is here reproduced.

The named veins developed in the mine are the Union Hill, whose identity is well established to the 600-foot level at the shaft and to the 800-foot level west of the shaft; the Greek-Tungsten, which has been found on all levels; the Lucky-Cambridge, early worked through the Lucky and Cambridge shafts and intersected by crosscuts on the 600- and 1,200-foot levels; the Georgia vein, which appears possibly to be a footwall split from the Union Hill; and the Back and Gold Point veins, which are cut by footwall crosscuts on the 800-foot level.

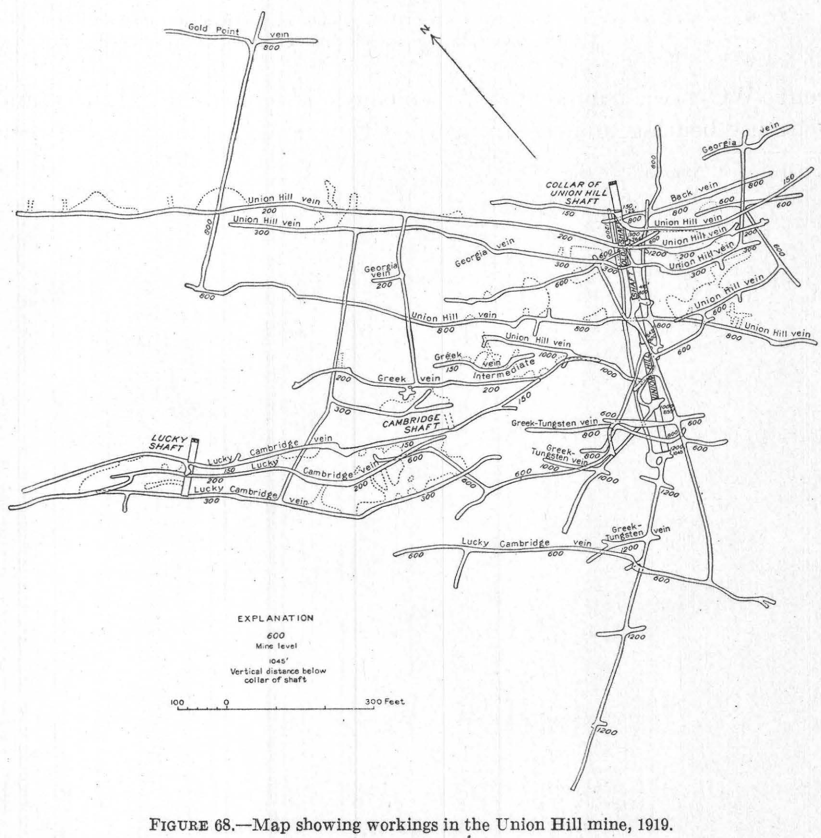


FIGURE 68.—Map showing workings in the Union Hill mine, 1919.

The Greek-Tungsten vein is of interest because of the scheelite it carries. According to MacBoyle,[87] the

[86] Logan, C. A., op. cit., p. 127.

[87] MacBoyle, Errol, op. cit., p. 255.

scheelite stringer is 2 to 7 feet wide During the World War 8 tons of hand-picked scheelite, averaging 1½ percent WO_3, was mined.[88] A polished specimen of scheelite-bearing quartz from this vein and a thin section of the ore are shown in plate 12, *A* and *B*. MacBoyle credits the Union Hill mine, including the Lucky and Cambridge mines, with a total production of between $500,000 and $750,000.

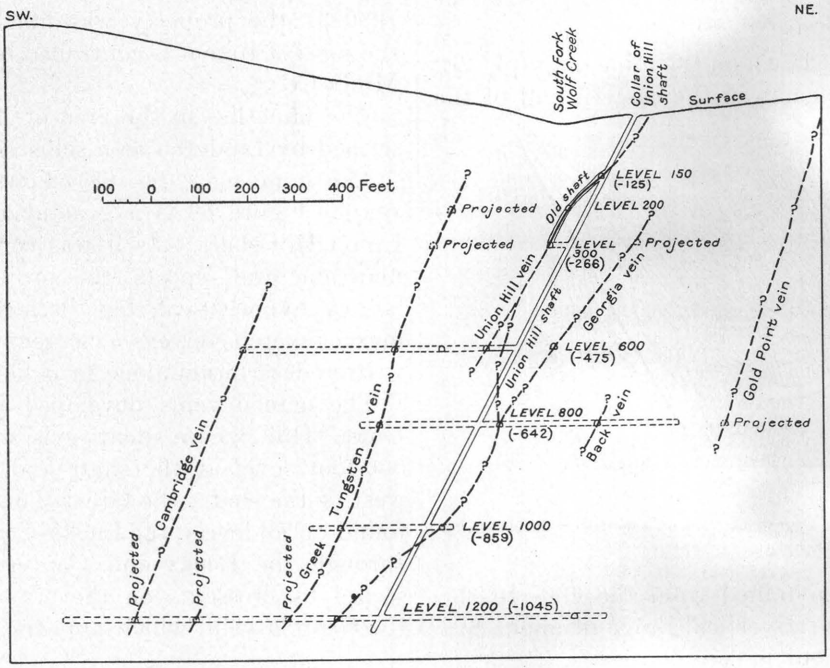


FIGURE 69.—Generalized section through the Union Hill shaft. As the mine was inaccessible at the time field work in the district was done, this section has been compiled from working maps and oral descriptions and is intended only to show the relative position of the veins.

[88] Hess, F. L., unpublished notes.

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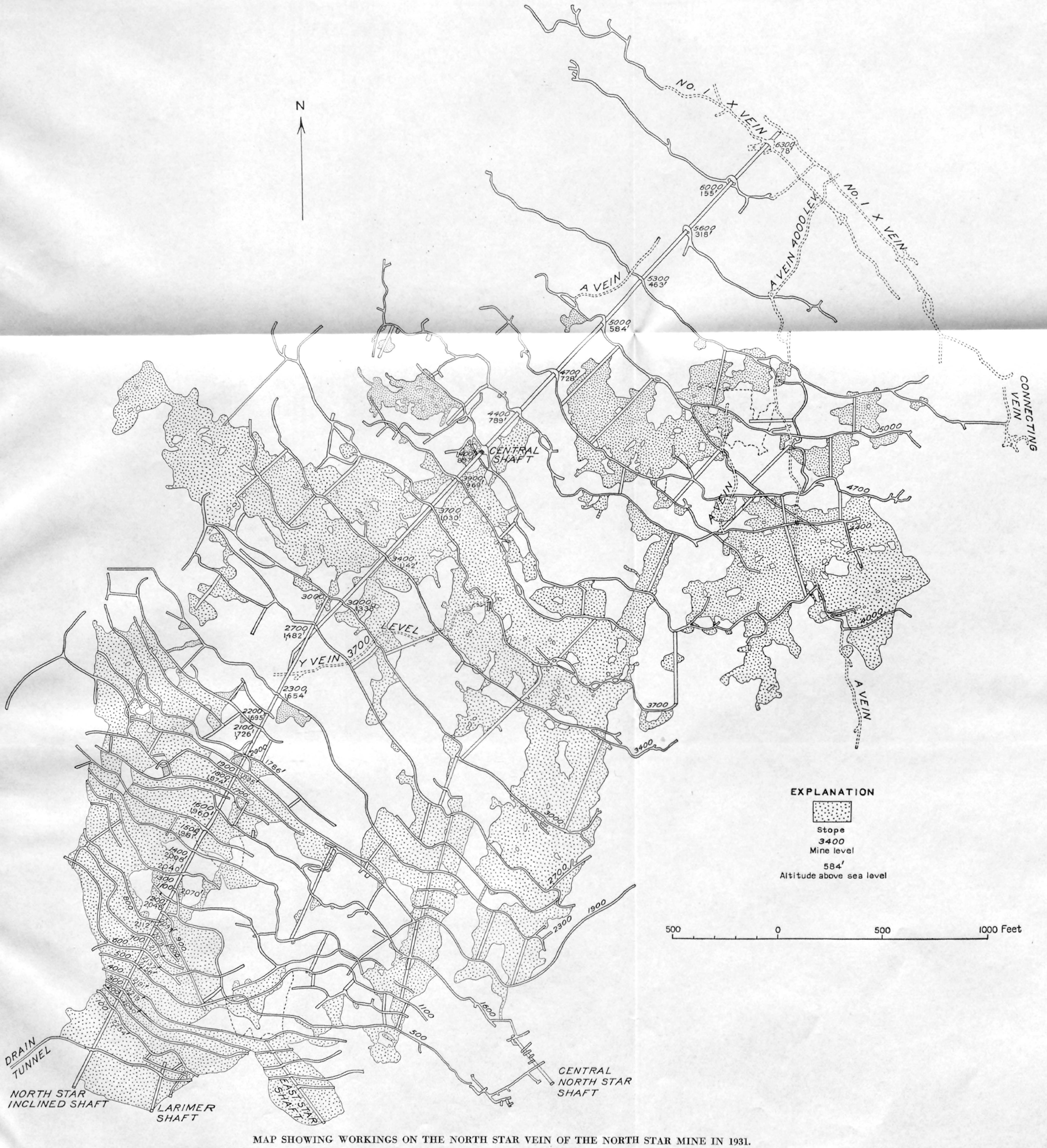
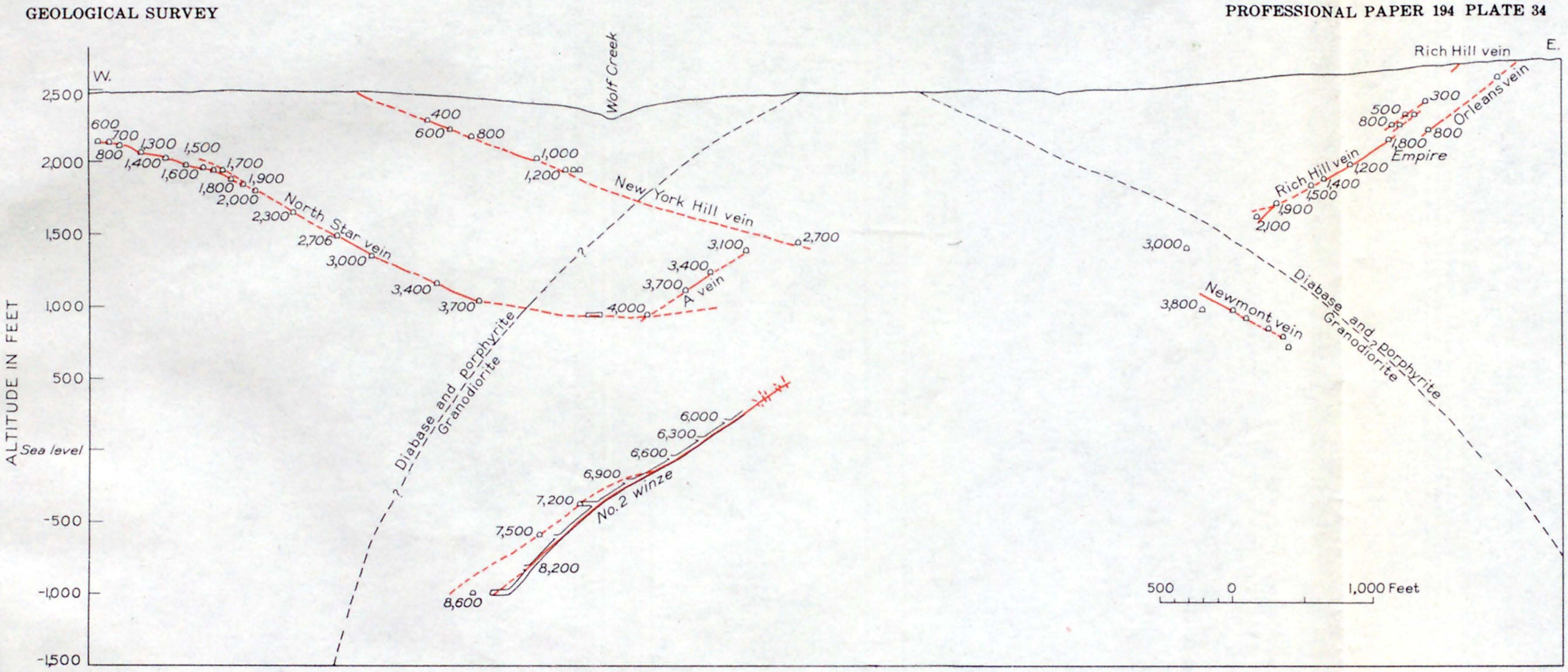
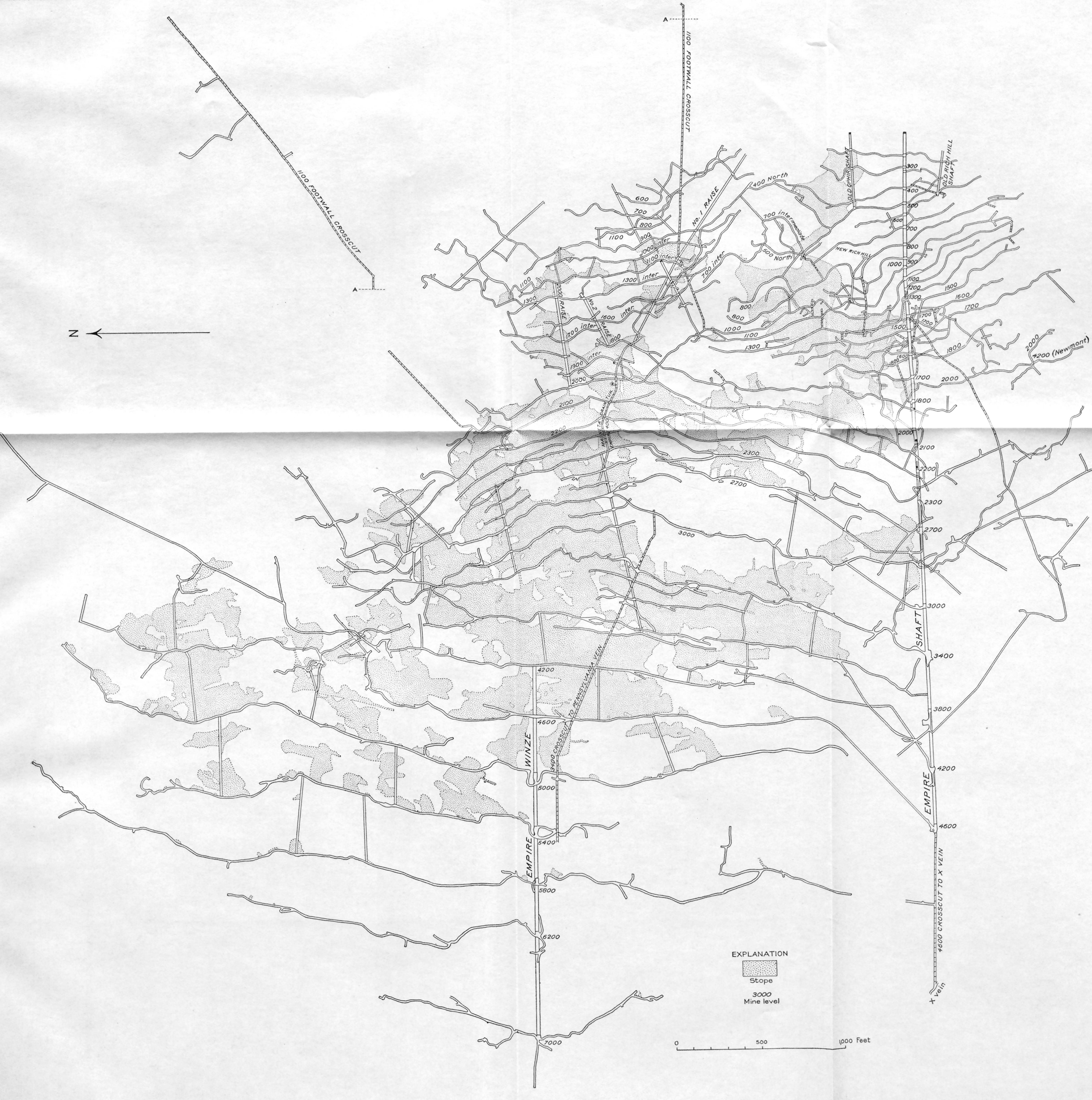


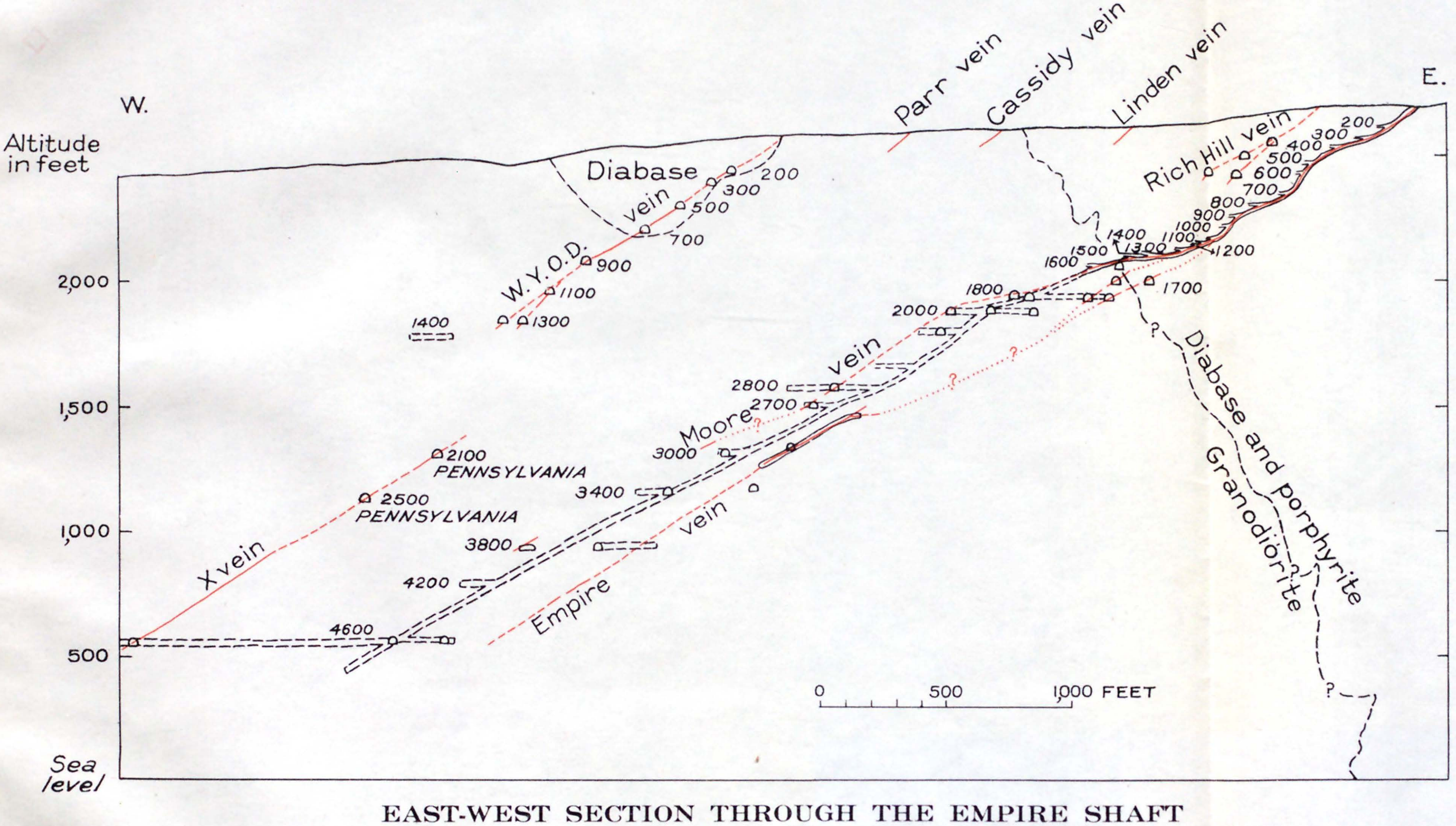
MAP SHOWING WORKINGS ON THE NORTH STAR VEIN OF THE NORTH STAR MINE IN 1931.



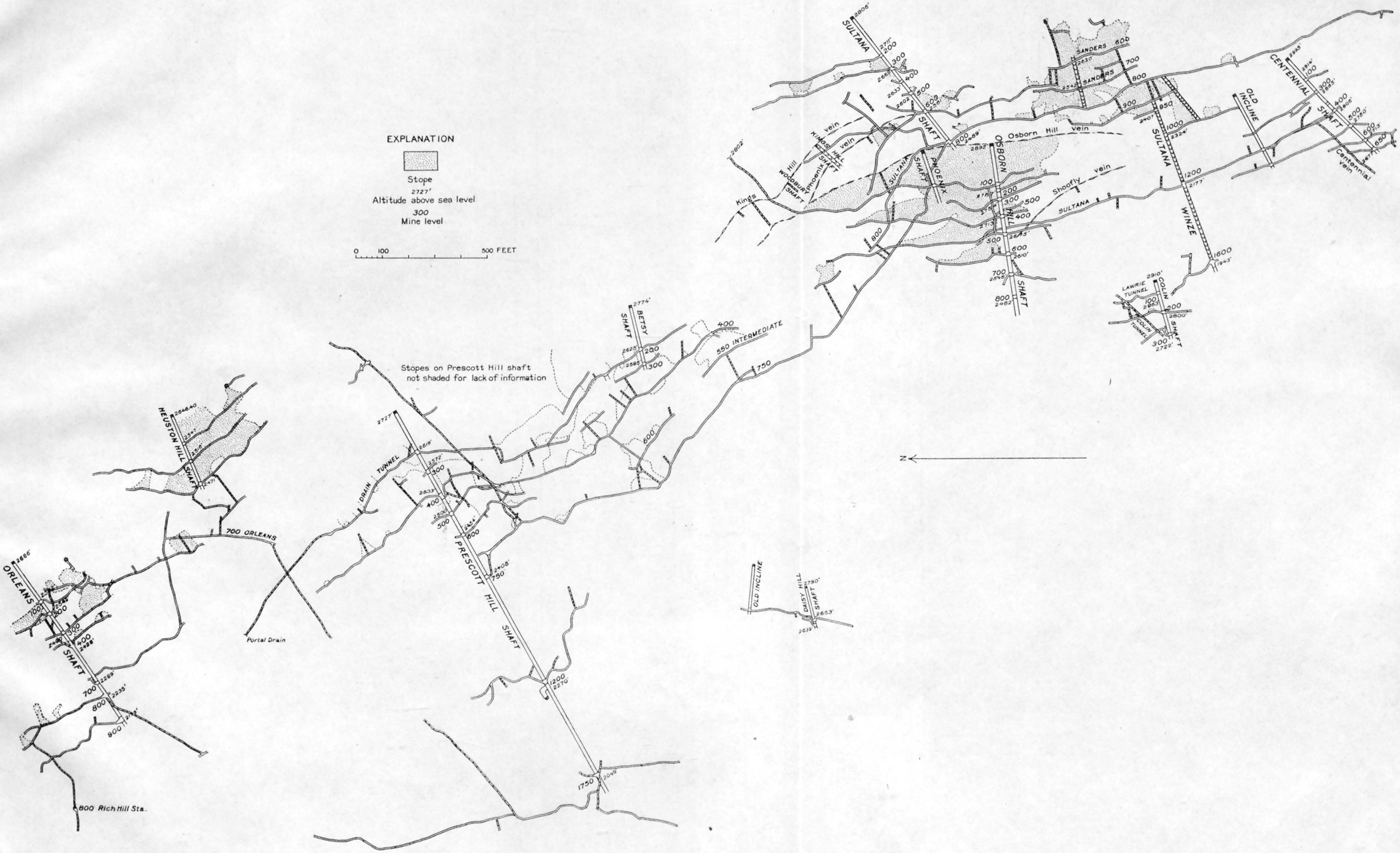
SECTION THROUGH No. 2 WINZE, NORTH STAR MINE



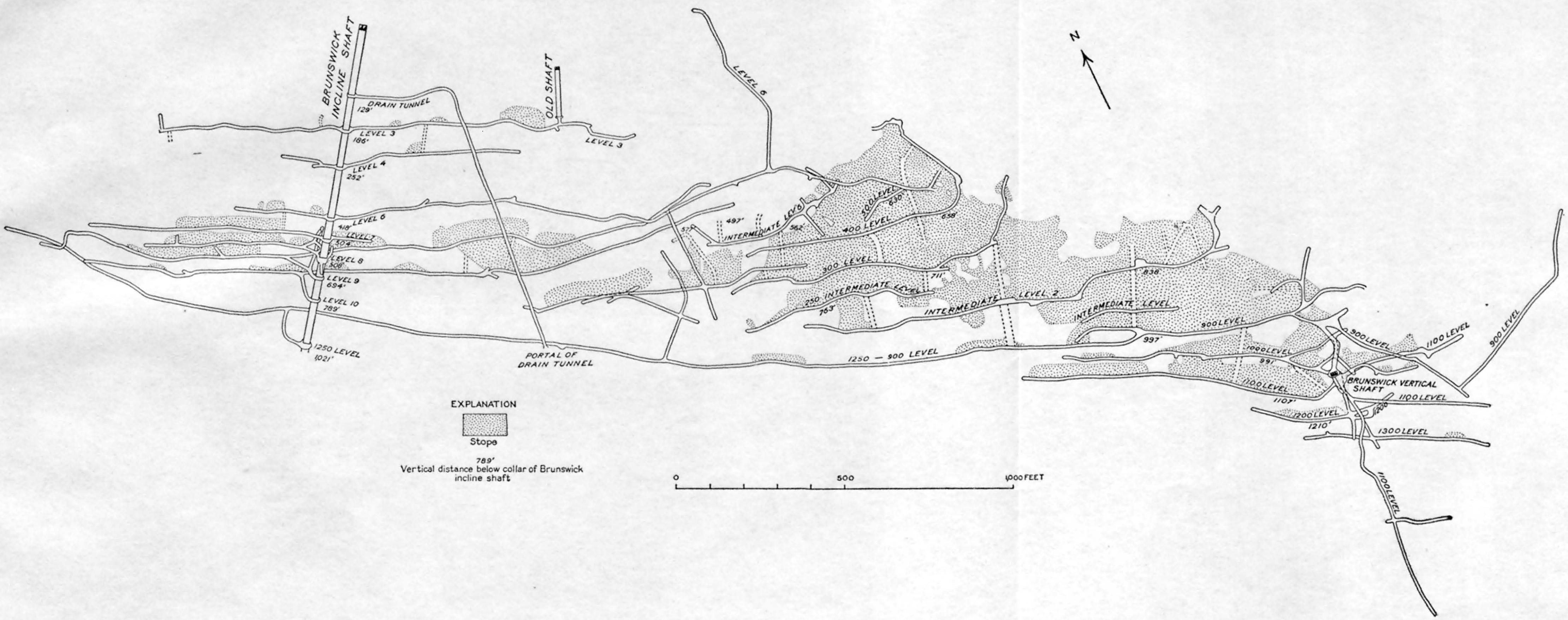
MAP SHOWING WORKINGS IN THE EMPIRE MINE NORTH OF THE EMPIRE SHAFT.



EAST-WEST SECTION THROUGH THE EMPIRE SHAFT



MAP SHOWING WORKINGS IN THE DAISY HILL, ORLEANS, HOUSTON HILL, PRESCOTT HILL, BETSY, SULTANA, OSBORN HILL, CENTENNIAL, AND CONLIN MINES.



MAP SHOWING WORKINGS IN THE BRUNSWICK MINE, 1924.