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RELATIONS OF STRUCTURE TO MINERAL DEPOSITION AT THE INDEPENDENCE MINE, ALASKA

BY
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RELATIONS OF STRUCTURE TO MINERAL DEPOSITION AT THE INDEPENDENCE MINE, ALASKA

By WALTER CLERICUS STOLL [1]

ABSTRACT

The gold quartz vein at the Independence mine in the Willow Creek district is one of several occurring in the quartz diorite batholith of late Mesozoic or early Tertiary age that forms the Talkeetna Mountain range of south-central Alaska. The vein proper, which occurs in a fault zone, has a maximum known thickness of 8 feet. The average strike is N. 10° W. and the average dip is 25° W. The maximum observed dip is 55° W. The attitude of the vein is modified by three undulations or rolls trending NW–SE. The internal vein structure is a result of minor faulting that occurred during and after mineralization. Ascending solutions along the fault zone caused intense alteration of the wall rock followed by deposition of quartz and minor amounts of pyrite, arsenopyrite, calcite, scheelite, sphalerite, galena, and native gold.

Three types of vein areas occur in the mine: Areas of compression, typified by absence of quartz, areas typified by the presence of a varying thickness of vein quartz, and transitional areas typified by alternating bands of vein quartz and country rock or by inclusions of wall rock in the quartz vein. These three types of areas are found in parts of the mine where the dip of the vein is high, low and intermediate, respectively. The maximum thickness of quartz occurs where the dip is lowest. The maximum tenor of gold occurs where the dip, as compared with immediately adjacent areas, is greatest.

Study of thin sections of the vein material shows that the gold occurs in zones of microbrecciation within the quartz.

These were caused by faulting subsequent to the deposition of the quartz and are most prevalent in areas of steepest dip. It is suggested that the horizontal stress tending to crush the vein would be most effective in areas where steeper dips caused the vein to be more nearly normal to the direction of the horizontal force. At two places where quartz was present, but having low gold tenor, it was noted that late shearing had taken place in the wall rock instead of the quartz. At another place late shearing had provided a "by-pass" which may have prevented the gold-bearing solutions from reaching the quartz vein.

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[1] This report was originally prepared by Mr. Stoll in partial fulfillment of certain academic requirements for an advanced degree in the Massachusetts Institute of Technology. The results of his work have significance not only in interpreting the structure and geologic conditions at the mine specifically described but also in their broader application to the whole problem of mineralization in the Willow Creek district, Alaska. As here presented, some abridgment has been made in the text, and certain illustrations used in the original report have been omitted.—Philip S. Smith, Chief Alaskan Geologist.

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INTRODUCTION

The Willow Creek mining district, in which is situated the Independence mine, lies in south-central Alaska about 20 miles from the Knik Arm of Cook Inlet. (See fig. 8.) Anchorage, one of the larger towns of the Territory, is aproximately 45 miles south of the mining district. Smaller towns nearby include Wasilla, on the Alaska Railroad, and Palmer, a Government-sponsored agricultural community in the Matanuska Valley. The Willow Creek district forms the

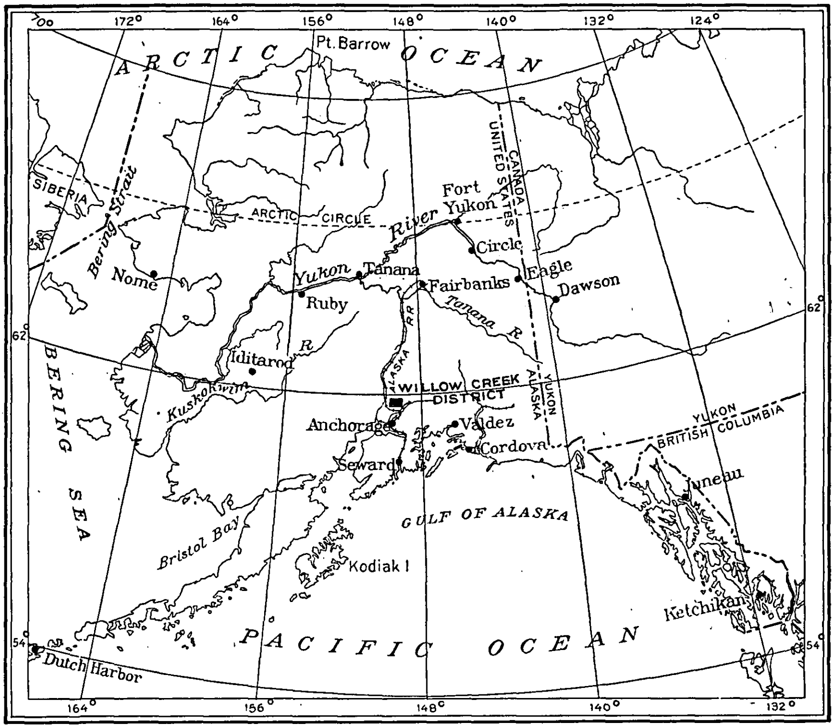

FIGURE 8.—Sketch map of Alaska showing location of Willow Creek district.

southwestern part of the Talkeetna Mountains. The topography is rugged. Elevations within the district range from 1,500 feet in the Little Susitna Valley to 6,000 feet at the crests of the highest peaks in the northeastern part of the area.

The observations upon which this report is based were made by the writer at the Independence mine, during the summer of 1940. R. L. Funk, mining student, was of great assistance in underground work. Descriptions of parts of the mine where the vein has been removed by stoping or which for various reasons are now inaccessible were supplied by A. G. Dodson, mine foreman. G. H. Gilson and N. E. Nelson, mining engineers, have kindly informed the writer of certain pertinent developments that occurred after his departure from the mine at the end of the summer. Information as to certain of the larger geologic features of the Willow Creek district was derived mostly from Geological Survey bulletins by Capps [2] and Ray.[3] Underground photographs were taken by Mr. Web Harrison of Seattle. Prof. W. H. Newhouse, of the Massachusetts Institute of Technology, has kindly given valuable criticism and aid throughout the preparation of the report.

GEOLOGIC SETTING

The Talkeetna Mountains are carved largely from an extensive granitic batholith, which was probably emplaced in late Mesozoic or early Tertiary time. Part of this quartz diorite mass forms the northern half of the Willow Creek district. At the southern border it intrudes mica schist, which is probably of pre-Cambrian age. Along the flank of the mountains, both the schist and the granitic rocks are overlapped by Eocene conglomerate, arkose, and shale, with interbedded small lava flows. The Tertiary strata are tilted southward, locally gently flexed, and cut by later faults. Quartz veins of several types and dikes of dacite, dacitic aplite, and pegmatite cut the quartz diorite and the schist. A few basic dikes have also been noted. A prominent feature of the batholith is well-marked rhombic jointing. Throughout most of the district signs of past glaciation are recognizable, and in places the disappearance of the glaciers has been so recent that little weathering or postglacial sculpturing has taken place. Quaternary glacial deposits and alluvium form the valley floors.

The commercially important gold quartz veins of the Willow Creek district so far as has yet been observed, are entirely contained within the quartz diorite. The veins occupy a northeastward-trending tract that extends across the northern half of the district. The strike of individual veins, however, may show strong departures from this average trend. Dips are generally northward or westward, the average inclination of individual veins ranging from 20° to 45°. The minable veins are of the mesothermal class as defined by Lindgren. Native gold, occurring free in quartz or occluded in sulfides, is the only important economic mineral. An insignificant amount of silver is recovered. Three deposits are being exploited successfully, and others are in stages of exploration and development.

Large-scale post-mineralization normal faults that strike approximately northwest have cut the vein belt into blocks, each block being separated from the adjacent ones by wide fault zones dipping steeply

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[2] Capps, S. R., The Willow Creek district, Alaska: U. S. Geol. Survey Bull. 607, 86 pp., 1915.

[3] Ray, J. C., The Willow Creek gold lode district, Alaska: U. S. Geol. Survey Bull. 849–C, pp. 165–229, 1933.

to the northeast. The larger faults are spaced at intervals of about 1,200 to 1,500 feet. One of these is the Martin fault, which is exposed in the Independence workings. This fault zone dips on an average of 50° and through a width of more than 100 feet exhibits intense gouging and shattering.

INDEPENDENCE VEIN

GENERAL FEATURES

The Independence vein is a gold quartz vein occupying a low-dipping, narrow, shear zone in quartz diorite. The vein is of the mesothermal class, and consists mainly of quartz with minor amounts of sulfides, which make up only a few percent of the weight of ore as mined. The ore minerals include pyrite and lesser amounts of scheelite, arsenopyrite, sphalerite, galena, and native gold. The average tenor of the ore as mined is about an ounce of gold to the ton. The fineness of the mill bullion runs about 900 after extraneous copper scrap is deducted. Hydrothermal alteration of the granitic country rock has resulted principally in the development of chlorite, sericite, carbonates, and pyrite.

The Independence vein is one of a series of similar subparallel veins that crop out on the west wall of Fishhook Creek Valley. (See pl. 13.) The Snowshed vein lies about 70 feet beneath the Independence at one place, and the Skyscraper vein lies 300–500 feet above the Independence, distances being reckoned normal to the plane of the veins. Between the Skyscraper and the Independence veins is the Blacksmith Shop vein. Scattered outcrops point to the existence of still other lodes belonging to the westward-dipping system in the vicinity of the Independence mine. All these veins apparently represent primary channels of circulation of the quartz- and gold-bearing solutions, in contrast to the fractures that branch from and are subsidiary to the principal lodes. Each vein considered as a whole occupies a fracture zone composed of a main shear and various subordinate branching fractures.

The average strike of the Independence vein is about N. 10° W. and the average dip about 25° W. The strike varies, however, because of undulation of the vein. The dip, likewise, is variable, but the variation from point to point in most cases is not great. The steepest dip measured is 55° W. and at the opposite extreme, a dip of 2° E. was observed at one working face. Laterally, the vein has been partly explored over a length of about 2,800 feet. In depth, ore has been developed on the 1,400 level, which is about 1,100 feet down the dip from the highest outcrop of the vein on Granite Mountain.

The vein is not a simple filled fissure. Repeated shearing, replacement of wall rock, and local open-space filling have resulted in a variety of internal structures. Major surfaces of shear movement have not been entirely restricted to the immediate vicinity of the principal lode; in places they have diverged from the main fracture to form subparallel shear zones, which may or may not contain quartz. Most of the larger subordinate veins lie in the footwall of the main vein.

The width of the Independence vein is extremely variable. The widest exposure of vein quartz seen by the writer measured 8 feet. At some places underground, however, the proximity of two or more zones of movement and percolation of solutions has given rise to a mineralized zone as much as 15 feet wide, only a few feet of which is vein quartz, the remainder altered wall rock. At other places the vein over distances of several hundred feet along the strike is merely a narrow shear zone containing little or no vein quartz.

Decided undulations, or rolls, are a notable structural feature of the vein. Up to the present three principal rolls have been outlined by drifting at various levels. The axes of these undulations are shown in plate 14. The curvature, when projected upon a horizontal plane, is accentuated, because of the gentleness of the dip. In the northernmost roll (A, pl. 14), post-mineral faulting has further exaggerated the curvature on the 840, 900, and 960 drifts. The origin of this structure is not known to the writer. Folding of the fissure or partial control of shearing by earlier jointing have been both suggested as causes of deflection of the strike.

Between the rolls the vein extends without major deviation in strike or dip, and the small variations appear to be without continuity or structural significance. Deflections of strike and dip, combined with the effect of movement along the vein, were, however, of paramount importance in causing localization of quartz and, to a lesser extent, of gold.

The hanging wall of the Independence vein has moved intermittently up the dip and southward relative to the footwall. This is shown by the offset of intermineralization cross faults and by the strike and appearance of the striations at various places on the vein walls. Movement along the vein changed in direction from time to time and from place to place, as is shown by variations in the strike of different sets of striae. Most of the movement of the hanging wall appears to have been the result of pressure from one direction or another in the northwest quadrant. At one locality, however, the striae indicate strong southward strike-slip of the hanging wall combined with small normal displacement. The net movement has probably been a combination of thrust and southward strike-slip of the hanging wall over the footwall.

As has been mentioned, branching fractures stem from the main shear in both walls, especially the footwall. In one place at least, namely, the footwall branch vein on the 1100 level (D, pl. 14), the position of a minor vein was probably controlled by the curvature of the main vein. Southward movement of the hanging wall against the buttress afforded by the nearby eastward-striking section of the main vein possibly started tearing along the base of the buttress. This tear, modified by later shearing, is now marked by the footwall vein D.

Small-scale faulting of the vein took place throughout the epoch of vein formation and afterward. Faults are very numerous but are usually little hindrance in mining except in a few places where offsetting of 50 to 100 feet has occurred. The strike of the faults is either parallel or transverse to the strike of the vein, and displacement may be normal or reverse, more often normal. Dips are generally steep. Bending of the vein sometimes accompanied the displacement. Small intermineralization faults show offset of the vein. The faults do not appear to have exerted any important influence in localizing mineral deposition.

MINERALIZATION

In many places the quartz diorite wall rock of the vein is intensely altered, although the width of the altered selvage in either wall is ordinarily not more than a few feet. Most of the inclusions in the vein are greatly altered and replaced by quartz. In an early stage of the alteration process, biotite, the dominant ferromagnesian mineral of the country rock, was changed to green chlorite, and at a later stage the chlorite was changed to muscovite, releasing minute rutile needles, some of which show knee twins. Associated with the rutile is a mineral of prismatic, sometimes elongate, outline of high relief and birefringence, and of whitish color in reflected light. Extinction apparently is parallel to crystal outlines, although not distinctly so because of dispersion effects. This mineral is probably octahedrite or brookite. Pyrite is commonly concentrated near the site of a former biotite crystal. Arsenopyrite is present too, as euhedral crystals. Plagioclase feldspar was affected by sericitization at an early stage. Intense alteration has obliterated the feldspar entirely, and its site is occupied by a felted mass of fine quartz and sericite, commonly containing many patches of carbonate. Some albitization of plagioclase may have taken place. The hornblende is altered in the same way as the biotite, but the quartz and the apatite appear largely unaffected. Calcite veinlets cut all of the other minerals.

Among the ore minerals within the quartz vein, pyrite was the earliest, and scheelite also was probably early. Fine-grained chlorite was deposited in early breccia zones within the quartz. (See pl. 16.) Late fracturing of the quartz allowed the rise of solutions carrying sphalerite, galena, and gold, gold being the latest ore mineral. Some tetrahedrite is probably present. A small influx of sericite and fine-grained quartz accompanied or slightly preceded the rise of solutions bearing the ore minerals.

INFLUENCE OF STRUCTURE ON THE DISTRIBUTION OF ORE

LOCALIZATION OF QUARTZ

Examination of the Independence vein reveals that in the localization of vein quartz three principal types of vein areas may be distinguished. In areas of the first type compression of the hanging wall against the footwall was effective throughout the period of mineralization. Vein quartz is entirely absent, or is present in very small quantity. In these areas, the internal vein structure shows more or less intense shearing of the country rock and formation of gouge along individual shear surfaces. Hydrothermal alteration is usually not extensive in the walls of the sheared zone. The zone itself may range in width from a few inches to several feet, depending upon the number of shear surfaces that have participated in the movement.

In areas of the second type vein quartz of locally varying thickness forms a sheet that is continuous, with the exception of small pinched areas, and extends over thousands of square feet. The thickness of such continuous quartz sheets may range from 6 inches to 8 feet. Internal structure in many of these areas is characterized by unsupported angular or tabular inclusions of altered wall rock in the quartz matrix.

Areas of the third type are distinguished by scattered and winding quartz stringers in the shattered and sheared country rock of the vein zone or in some places by subparallel, narrow bands of quartz which are separated by wider bands of altered country rock. Some areas of this kind are gradational between areas of compression and areas of sheet quartz; others occur independently as small tracts within larger areas of either of the other types.

The relationship of areas of the three types is shown in plate 15. The quartzless areas are areas of compression, or bearing of wall against wall, the weight of the hanging wall having been mainly supported by the footwall during the period of faulting and mineralization. The quartz areas were formerly zones of looseness and brecciation that formed channels through which rising hydrothermal solutions percolated and deposited their dissolved minerals when the physicochemical environment became favorable, whereas the compressed areas, because of their tight and gouged nature, did not permit the entry of solution in appreciable volume.

The compressed and quartz-bearing areas differ in their relation to strike and dip, as may be seen by reference to plate 15. Quartz bodies, in general, occur in areas in which the dip is flatter than in compressed areas. Although the range of dip is considerable, where dip relations have beeen fully investigated the average dip in quartz-bearing areas is flatter than in adjacent compressed areas. Difference of dip in adjacent areas, not absolute angle of dip, is the main criterion for comparison.

The influence of variation in strike is not so well marked as is the influence of variation in dip; however, compressed areas were observed on the north limbs of the two southernmost rolls (B and C, pl. 14). Variations of dip and strike mutually modify each other in their effect upon the localization of quartz.

The factors that enter into the formation of tight and loose areas along faults and the significance of these factors in the study of ore deposits have been discussed by Newhouse.[4] They are initial irregularity of the fracture surface and direction and amount of fault movement in the vein. In the Independence vein, movement of the hanging wall has been up the dip and southward. Those sections of the vein that strike more toward the west or that dip more steeply than adjacent sections theoretically should be compressional zones, and such is observed to be true.

A noteworthy feature of the areal distribution of the compressed areas is illustrated in plate 15. Underground observation, supplemented in some cases by a conservative amount of extrapolation, indicates that the compressed zones are isolated, whereas the quartz areas are continuous and envelop the tight zones much as a body of water surrounds a group of islands. Such a relationship emphasizes the former function of the quartz areas as the continuous channelways for rising hydrothermal solutions.

Areas of compression may occur through fault movement in insufficient amount to totally displace from each other a footwall and hanging wall that have companion curves in the vein fault of a given irregularity. On the other hand, fault displacement may be great enough to move the curve in one wall of the vein beyond the companion curve in the other. In this case, also, local compressed areas may conceivably be formed, but the two walls of a given compressed area would not be companion curves of the original vein fracture. Tight areas of this kind would be the result of a chance coming together of complementary irregularities of the vein walls. In reverse faults, compressed zones produced in either manner would be areas of relatively steep dip.

The actual net amount of movement in the Independence vein is not known because of the absence of recognizable markers or points of reference. The writer believes, however, that the major compressed

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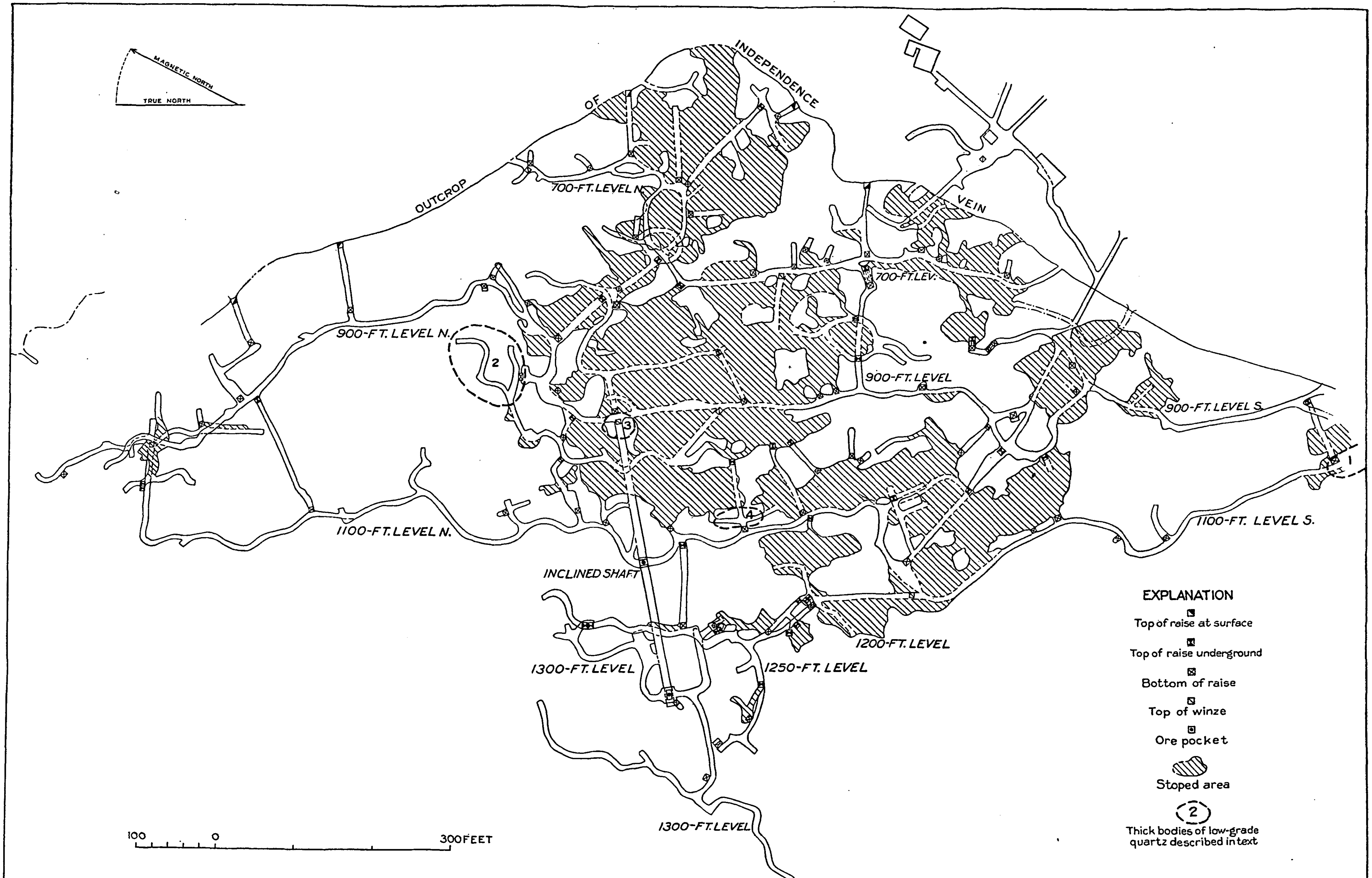
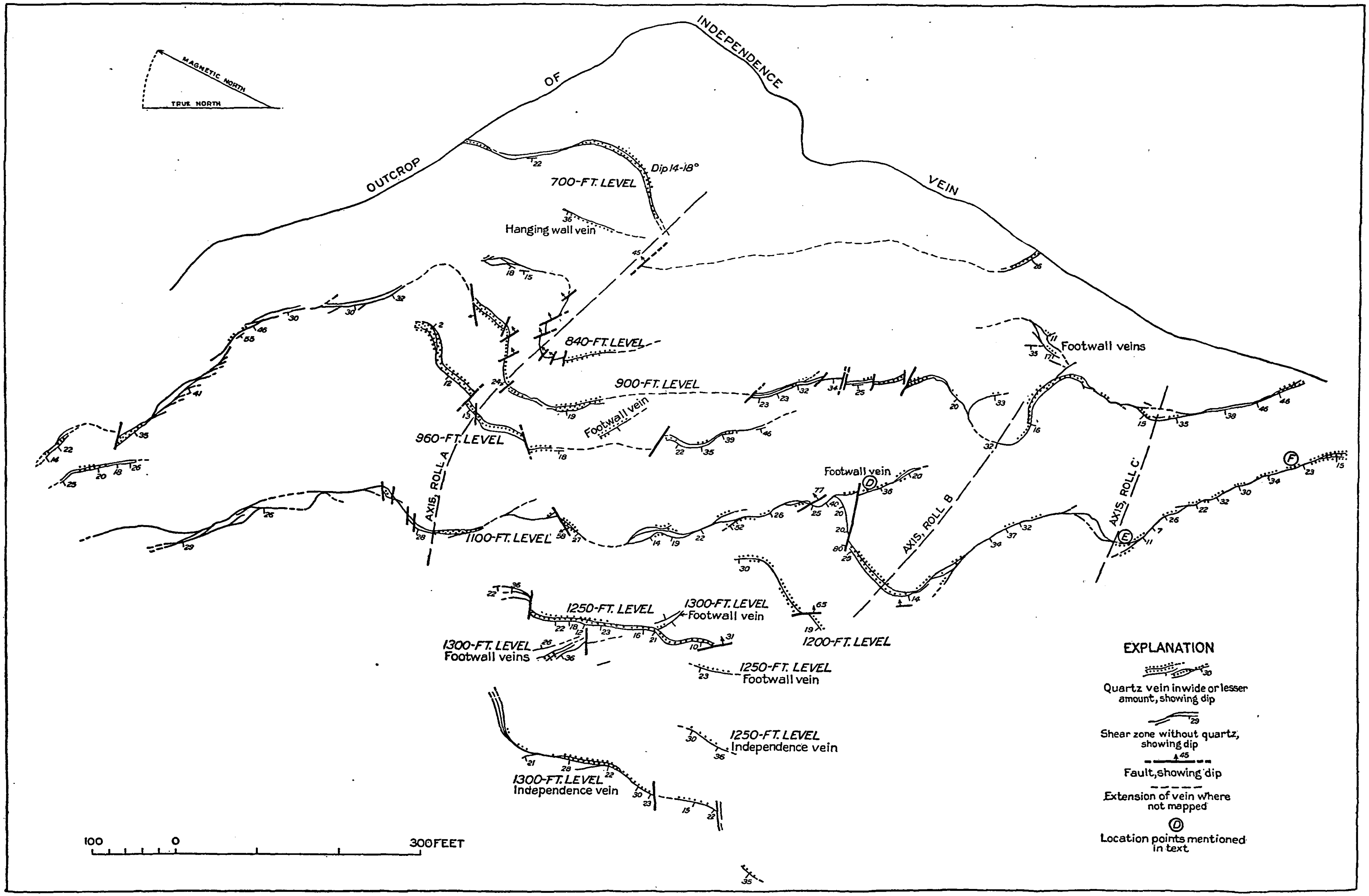
[4] Newhouse, W. H., Openings due to movement along a curved or irregular fault plane: Econ. Geol. Vol. 35, pp. 445–464, 1940.



PLAN OF WORKINGS IN NORTHERN PART OF INDEPENDENCE MINE, WILLOW CREEK DISTRICT.

(Face p. 208)



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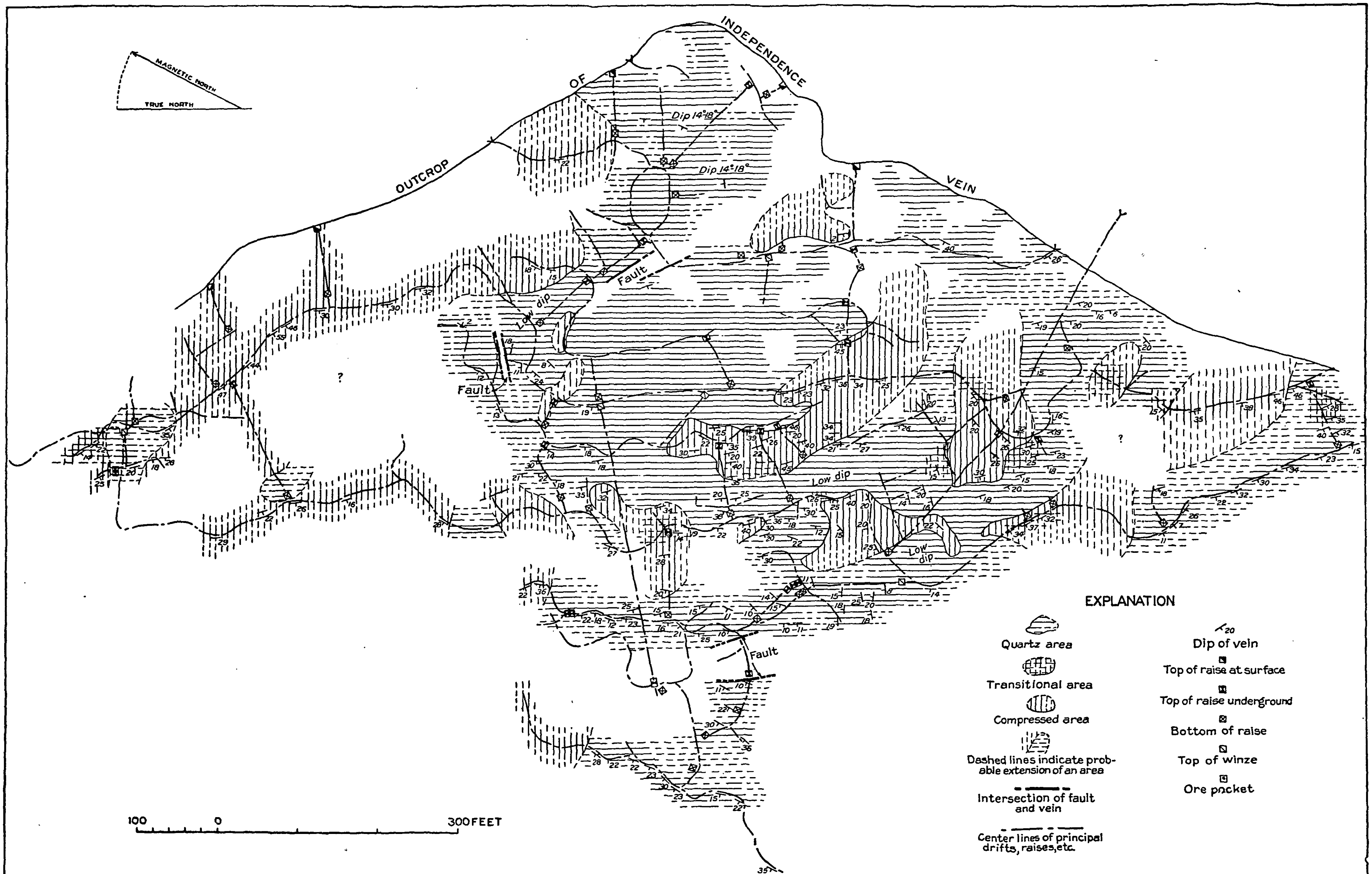
DIAGRAMMATIC SKETCH SHOWING STRUCTURE OF VEIN IN INDEPENDENCE MINE.



MAP OF INDEPENDENCE MINE SHOWING DISTRIBUTION OF QUARTZ.

(Face p. 208)

zones are probably areas in which companion curves of the original vein fracture are partly in contact. Small pinched areas, on the other hand, probably are caused by irregularities of small dimensions as compared with the total amount of movement in the vein; hence they are the result of a fortuitous juxtaposition of footwall and hanging wall irregularities of similar attitude. It is believed that movement in the vein fault of an amount greater than the dimensions of the larger tight areas would have resulted in a shear zone of different structure from that observed in the Independence mine. The rather close correspondence in strike and dip between the walls of the vein throughout the mine, considered with the lack of shattering in the walls adjacent to the immediate limits of the vein, seem to indicate that original companion curves of the larger sort are partly in contact. Were this not so, sharp divergence of the vein walls might be expected here and there. Of course, local, more or less gradual divergence of footwall and hanging wall is present, but this is to be expected in view of the relative movement of the walls that has occurred from time to time with resulting partial offset of companion curves. Moreover, intermineralization crossfaults that are offset by the vein commonly show only small displacements. Two such faults in which the offset parts could be correlated definitely, showed displacements of about 5 feet. A few other faults, whose parts could be matched with less certainty, showed offsets of 10 to 15 feet.

LOCALIZATION OF GOLD

Gold ore shoots are mainly localized within the quartz areas but are not necessarily entirely coextensive with the quartz. Moreover, tight areas adjoining ore shoots may themselves form ore for a few feet into their interior. Assays of wall rock and of sheared material from compressed areas of the vein as often as not will show a trace or more of gold. Transition zones of altered rock traversed by irregular quartz stringers are commonly of sufficient tenor to constitute ore. The condition is that of a fracture zone widely permeated with gold in small amount, but with the commercial ore shoots almost entirely restricted to the zones of refractured quartz that form the major parts of the quartz areas themselves. In general, quartz is ore, with some notable exceptions. Comparison of plates 13 and 15, which show, respectively, extent of ore shoots (stoped areas) and extent of quartz areas, will bear out this statement with the reservation that some ore still stands unmined in certain recently opened ground. The localization of gold mainly in the quartz is, of course, a common phenomenon.

Within an ore shoot, the assay value of various samples of ore may vary widely. A sample cut at one spot may assay 1 ounce of gold, for instance, while another sample cut only 3 feet away may assay 0.1

ounce or less. Channel sampling may indicate the presence of an ore shoot by showing in a given area a more or less wide range of assay values, some or most of which are high; but sampling within an ore shoot is not a reliable guide as to what should be mined and what left unmined. Where sampling of a limited block of vein shows a liberal scattering of high assays, the entire block is mined regardless of the low assays that are interspersed with the high ones. Mining results have shown this procedure to be justified. At the present time, the vagaries of the distribution of gold within the quartz of an ore shoot remain unexplained. Where ore is of extremely high grade, all assays along the vein may be high, but the variation from sample to sample may be great. Some uniformity of assay values is found in barren or semibarren ground, where all samples assay low.

In addition to a consideration of the assay value, quartz that is to be mined successfully must, of course, be of reasonable width and continuity. The immediate problem is to explain the position of ore shoots and barren shoots as defined above. In those occurrences of barren quartz and ore, where the position of the ore appears to be related to the strike and dip of the vein, the problem seems answerable. For other occurrences no solution presents itself.

From an examination of thin sections of vein quartz it is apparent that the rise and deposition of gold in the vein was dependent upon late refracturing of the quartz. Gold and some of the associated ore minerals occur in or near microscopic zones of shear and brecciation within the vein quartz, and they replace the quartz. High-grade quartz is minutely fractured along closely spaced microbrecciation zones. A single thin section of such ore may be traversed by two or three such zones of microbrecciation.

A late recurrence of movement caused by forces presumably of the same nature as those that caused earlier movements generally would be expected to disturb the old zones of weakness rather than to create new faults. It is true that renewed movement need not be limited to quartz areas, but may affect as well other parts of the vein. The brittleness and the strength of quartz under stress probably permit the continued existence of a transecting network of minute open channelways through the body of the quartz vein. Compressed areas, of gougy nature and subject to the brunt of the stress, largely prevent the passage of these late solutions just as they formerly prevented the entry of earlier solutions.

More in need of explanation than the occurrence of gold with the quartz is the existence of certain sections of quartz vein that are lacking in an appreciable content of gold. Of those sections of vein that have been explored up to the present time the sections characterized by exceptionally great thicknesses of quartz have been of such low tenor as to be not independently minable as ore. These thickest quartz bodies are the ones of lowest dip, as has been noted. Four such thick bodies of low-grade quartz are designated as areas 1, 2, 3, 4 in plate 13. Up the dip from these thick lenses, and probably down the dip as well, the quartz vein becomes thinner as the local dip increases, and here the quartz is enriched in gold.

The dependence of gold enrichment of the quartz upon late fracturing offers a clue to the cause of the barrenness or nearbarrenness of some of the thicker quartz bodies.

An assumed horizontal thrust of the hanging wall block against the top of the quartz vein may be resolved into two component forces. One component is parallel to the dip of the vein and tends to cause shear along or parallel to the vein walls; the other component is normal to the vein and tends to press the vein walls together. In the flatter dipping sections of the vein the first force component is great and the second small; whereas in the more steeply dipping parts the first component is diminished and the second is increased. As the hanging wall moves up the dip relative to the footwall, shear and brecciation ensue within the vein. In the flatter dipping areas of thick quartz, shear movement that started along some narrow zone in the vein would tend to continue along this initial narrow zone of weakness. Because of the smallness of the force component normal to the vein and because of the tendency of the hanging wall to move slightly away from the footwall as movement continues, friction on an initial zone of weakness and movement tends to be relatively small in a flat-dipping part of the vein. Steeper sections of the vein, on the other hand, are subjected to greater normal compressive force, which would tend to cause a more diffused fracturing of the quartz rather than localization of fracturing in a relatively narrow zone within the vein. This hypothetical relationship is illustrated in figure 9. Some such combination of forces has apparently operated during the en-

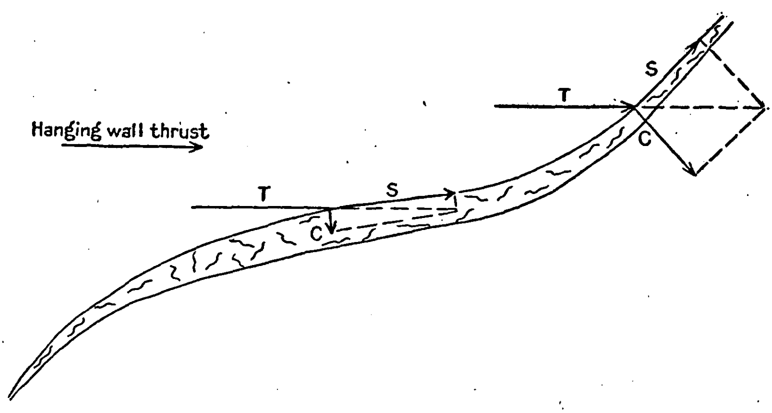


FIGURE 9.—Diagrammatic sketch showing disposition of the components of a horizontal thrust upon a vein of variable dip. T, horizontal thrust; C, compressional component; S, shearing component.

richment of the quartz above area 1 in plate 13. In the thick vein along the drift only sparse gold is found and that is limited to the upper fourth of the cross section, causing the vein as a whole to assay low. Up the dip from the thickest section of the lens an oreshoot occurs where assays across the vein show a marked increase in gold content. Four thin sections of quartz from the wide part of the vein show an absence of microbrecciation.

In areas 2 and 3 detailed examination and sampling across the vein should reveal late movement of a similar type. Concentration of late movement along a gouged zone on the hanging wall of the thick quartz vein may have effectively prevented any important refracturing of the quartz. At any rate, the writer considers that parts of the vein lying immediately down the dip from areas 1 and 2 are very likely spots for the occurrence of ore.

A somewhat different situation exists in area 4 (pl. 13). Here a gently dipping lens of quartz ranging from 1 to 3 feet in thickness is almost barren of gold over a considerable area. A narrow shear zone starts from the lens at its lower edge and branches into the hanging wall, where it lies roughly parallel to and a few feet above the vein. At a point farther up the dip, where the dip of the vein begins to steepen, the hanging wall shear zone converges with the vein. This small shear zone apparently has acted as a bypass along which late movement occurred rather than occurring within the quartz vein itself. At the upper edge of the barren lens, where the bypass shear zone and the vein converge and the dip of the vein increases, there was ore which has been stoped. Concentration of late movement along the small shear zone in the hanging wall of the low-dipping quartz lens prevented the fracturing of this body of quartz necessary to its enrichment by gold-bearing solutions. Two thin sections of the barren quartz show but slight late disturbance. Figure 10 illustrates diagrammatically the relations of vein and ore to the bypass shear.

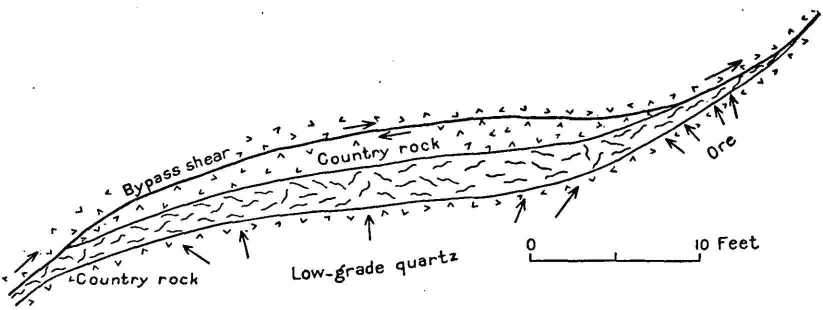
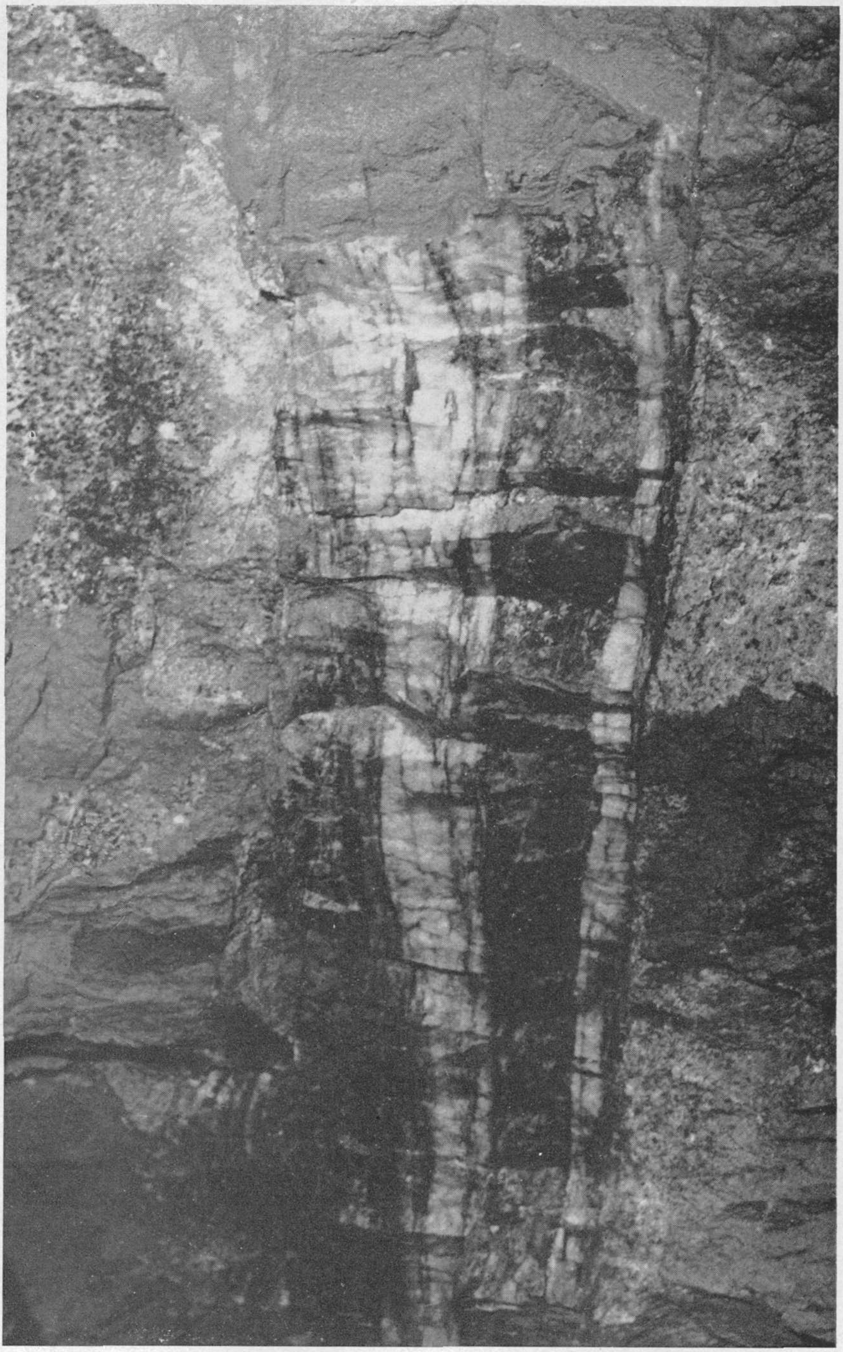


FIGURE 10.—Diagrammatic sketch showing relation of bypass shear to quartz vein.

The results of an attempt to correlate the evidence of late movement shown in thin sections with the grade of ore at the places where the specimens were taken are, for the most part, in accord with the



BANDED QUARTZ VEIN.

1,100-foot level south, near foot of raise 10. The dark bands contain chlorite introduced into quartz along parallel zones of brecciation.

LARGE FRAGMENT OF WALL ROCK SUSPENDED IN QUARTZ.
1,100-foot level south. Other smaller fragments may be seen in the quartz.

conclusions that were anticipated from the larger structural relations observed. Thin sections of high-grade ore almost always show intense microbrecciation. In ores of moderate grade microbrecciation of strong or of weak intensity is generally present, but sometimes it is lacking. Most sections of material from the thick barren lenses of quartz lack the cataclastic texture entirely; a few may show a weak micro-shear. The correlation, although imperfect, is definitely indicated qualitatively by these comparisons.

The section of quartz vein exposed along the 1,100 foot level of this south drift (between points E and F, pl. 14) is peculiar in that it is composed of alternating dark and light bands across its width. (See pl. 16.) The light bands are white quartz; and the dark bands are seen in thin section to contain chlorite which was introduced into the quartz along what are apparently broad, parallel brecciation zones, presumably of early origin. This part of the vein is but slightly mineralized with gold. Several high assays were obtained from parts close together, but the section as a whole is not ore. From the information now available, the writer cannot explain the scanty mineralization persisting over such a considerable length of quartz vein. This particular section is apparently an exception to the general theory that continuous areas of quartz are minable as ore, exclusive of thick bodies of low dip. Future development work will probably provide data upon which some explanation may be based.

Ferguson and Gannett,[5] summarizing the characteristics of the ore shoots of veins following reverse faults in the Alleghany District, California, state that, in several cases, the thickest lenses of quartz are not productive. In the Sixteen to One mine, quartz in the productive parts is thicker than the average, but the thickest swells in the quartz are nonproductive. These authors describe the productive part of the Eldorado mine as probably having a steeper dip than the average. In the Independence mine, however, the sections of steepest dip are barren of quartz, the flattest areas contain thick quartz but little gold, and the areas of intermediate dip carry less quartz but more gold. These generalizations are subject to modification in particular areas due to the influence of changes of strike and other factors that have been described.

The causes of localization of ore shoots in the Independence mine may be summarized as follows: Quartz areas have been the loci of deposition of late minerals because of the mode of fracture of the quartz. Thick quartz lenses, because of their low dip, have not undergone late fracturing to any considerable extent, and hence these parts of the vein remain unenriched. The relative barrenness of a banded

[5] Ferguson, H. G., and Gannett, R. W., Gold quartz veins of the Alleghany District, California, U. S. Geol. Survey Prof. Paper 172, p. 54, 1932.

quartz area remains unexplained at present. Where local dip increases to thick lenses, diffuse fracturing of the quartz and gold enrichment have occurred.

INTERNAL STRUCTURE OF THE VEIN

The most noteworthy features of the internal structure of the Independence vein are the extremely numerous inclusions of unsupported and altered wall rock in the quartz. These inclusions may be large or small angular fragments, or they may be long, slender bodies lying about parallel to the vein walls. The country rock of which the inclusions are constituted may be only slightly altered, with granitic texture clearly recognizable in the hand specimen, or it may be highly altered, the dark silicates having been wholly removed. Inclusions may be seen in all stages of digestion by the enveloping quartz, which replaces them. Some of the inclusions are mere ghosts, converted almost entirely to quartz.

The long, slender inclusions are interpreted as remnants of sheared, altered, and partly replaced country rock that remain after most of the surrounding sheared material had been entirely replaced by quartz. (See fig. 11.) The angular inclusions are relicts of the irregularly brecciated adjacent country rock partly replaced by quartz. (See pl. 17.)

In thin section, small brecciated fragments in the vein are seen to be almost wholly replaced by quartz. The fragments may be

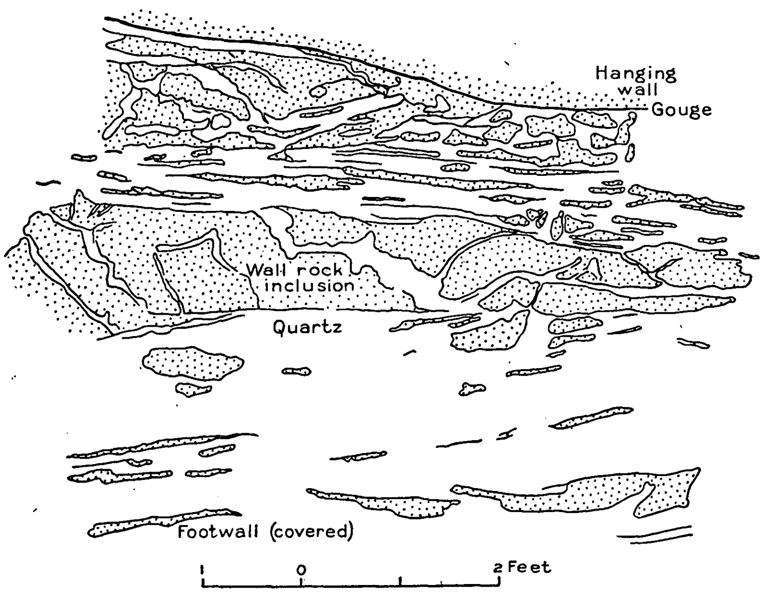


FIGURE 11.—Diagrammatic cross section of vein, 1,100-foot level south near foot of raise 12. Stippled areas are country rock; blank areas are quartz.

rounded, angular, or of irregular shape. Within their boundaries are generally concentrations of sericite, commonly with some carbonate, pyrite, or chlorite. Quartz, which constitutes the bulk of such an inclusion, is of variable grain size, but always smaller than the surrounding quartz matrix. Occasionally, a euhedral or subhedral crystal of quartz is seen to project from the matrix into the interior of an inclusion. Local patches of medium-grained quartz surrounded by coarser quartz may possibly represent a more advanced state of the replacement process, in which recrystallization of small grains has tended to produce the typical coarse texture of the vein.

Some of the narrow quartz veinlets, which in some places are to be observed cutting the altered rock of the hanging wall or footwall of the vein, appear to be of replacement origin. Megascopically, some of these veinlets are characterized by the presence of included delicate septa of wall rock. Two thin sections cut across the contact of one of these veinlets and its wall rock reveal the fact that quartz has indeed replaced the enclosing rock. On the wall rock side of the contact, quartz is seen to encroach upon sericitized plagioclase. The replacing quartz occurs as irregularly bounded masses, which may contain within and near their borders tiny relicts of unreplaced feldspar. The quartz projections into the feldspar may or may not be optically continuous. Some apparently unaffected sericite shreds inherited from the altered feldspar are contained within the quartz. Other quartz masses within the wall rock show, however, a higher stage of development in that their boundaries have become more regular and that sericitic and other inclusions have been expelled from the crystal to form concentrations around the borders of the grains. Within the transecting quartz veinlet itself, the usual coarse, hypidiomorphic granular texture prevails. In one section, two unreplaced relicts of sericitized plagioclase remain completely enveloped by the quartz veinlet. The contact is irregular in detail and in some places poorly defined.

The origin of these quartz veinlets appears to be as follows: Fracturing along one surface or several parallel closely spaced surfaces was accompanied by the introduction of quartz-bearing solutions that replaced the wall rock immediately adjoining the cracks.[6] Slight movement may have been repeated, especially where such veinlets are more than 1 or 2 inches wide. The replacing quartz at first was in the form of extremely irregular masses containing inclusions. Recrystallization ensued and was accompanied by the replacement of the inclusions and the formation of regularly-bounded quartz grains

[6] Goodspeed, G. E., Dilation and replacement dikes : Jour. Geol., vol. 48, pp. 175–195, 1940.

of increased size. The continued enlargement of individual grains and the complete removal of sericitic inclusions from the system produce the typical hypidiomorphic granular texture of the quartz vein.

CONCLUSIONS

The sequence of events which produced the Independence vein was probably as follows:

(1) Original fracturing and movement that took place along the vein fault started subsidiary breaks and developed tight and loose areas in the fault. This first stage was followed closely by the rise of hydrothermal solutions, which altered the country rock along the vein.

(2) Repetition of movement ensued and was accompanied by the rise of solutions bearing silica. These solutions were restricted mostly to the loosely brecciated and sheared channelways that now appear as the quartz areas of the vein. The solutions effected replacement of the shattered and sheared wall rock and filled small open spaces. This process was repeated several times.

(3) Still later, refracturing along the irregularly embrittled shear zone, permitted the rise of gold- and sulfide-bearing solutions, which deposited their load mainly in those portions of the quartz vein that happened to be fractured at that critical time.

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