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

by

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I 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. Anchorage, one of the larger towns of the Territory, is approximately 75 miles to the 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 part of the southwestern Talkeetna Mountains. The topography is of rugged aspect. Elevations within the district range from 1500 feet in the Little Susitna valley to 6000 feet at the crests of the highest peaks in the northeastern part of the area.

II GEOLOGICAL SETTING

The Talkeetna Mountains are carved largely from an extensive granitic batholith, which was probably emplaced in late Mesozoic or early Tertiary time (1)(2). Part of this massif, of quartz-dioritic composition, forms the northern half of the Willow Creek district. Its southern border intrudes mica schist of probable pre-Cambrian age. Along the southern flank of the mountains, both schist and granitic rock are overlapped by Eocene conglomerate, arkose, and shale, with interbedded small lava flows. The 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. A few dikes of basic appearance have also been noted. A prominent feature of the batholith is its well-marked rhombic jointing. The schist, as well as the granitic intrusive, is cut by quartz veins and dikes. Quaternary glacial deposits and alluvium form the valley floors.

The commercially important gold-quartz veins of the Willow Creek district are, so far as has yet been observed, entirely contained within the quartz diorite massif. The veins form a northeast trending belt across the northern half of the district. Individual veins, however, may show strong departures of strike from this average trend. Dips are generally northward or westward, with average figures for individual veins ranging between 20 and 45 degrees approximately. The minable veins are of Lindgren's mesothermal class. 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 successfully exploited at the present time, and others are in stages of exploration and development.

Large-scale post-mineralization normal faulting of approximate northwest strike has cut the vein belt into blocks, each block being separated from the adjacent ones by wide fault zones dipping steeply to the northeast. The faults are, in round numbers, 1200 to 1500 feet apart. One of these is the Martin fault, which is exposed in the Independence workings. This fault zone, dipping on an average of 50 degrees, has a width exceeding 100 feet over which is exhibited intense gouging and shattering.

III DESCRIPTION OF THE INDEPENDENCE VEIN

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 of quartz, mainly, with minor sulfides which amount to only a few percent of the weight of ore as mined. The ore minerals present include pyrite mostly, with scheelite, arsenopyrite, sphalerite, galena, and native gold. The tenor of the mined ore amounts to an ounce of gold per ton on the average. The fineness of the mill bullion runs around 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 is one of a series of similar, sub-parallel, veins which outcrop on the west wall of the Fishhook Creek valley. The Snowshed vein underlies the Independence by about 70 feet at one place, and the Skyscraper vein overlies the Independence some 300 to 500 feet, distances being considered normal to the planes of the veins. Between the Skyscraper and the Independence veins, a fourth one, the Blacksmith Shop vein, occurs. Other scattered outcrops point to the existence of still further lodes as members of the westward-dipping system in the vicinity of the Independence mine. All of these veins apparently represent primary channels of circulation of the quartz and gold-bringing solutions, in contrast to the fractures which branch from, and are subsidiary to these principal lodes. Each vein considered as a whole is 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 dip averages probably 25 degrees to the west. Great variations of strike are, however, marked by curvatures of the vein. Dip, likewise, is variable. The steepest dip measurement is 55 degrees to the west, while the opposite extreme of eastward dip at 2 degrees was observed at one working face. These, however, are extreme values; the variation of dip from point to point is not ordinarily very great. Laterally, the vein has been partly explored over a length of about 2800 feet. In depth, ore has been developed on the 1400 level, which is about 1100 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 developed a variety of internal structures. Major surfaces of shear movement have not been entirely localized to the close vicinity of the principal lode, but have sometimes diverged from the main fracture to form, in places, subparallel shear zones which may or may not show quartz. The larger of the subordinate veins usually lie in the footwall of the main vein.

The width of the Independence vein is extremely variable. Eight feet of vein quartz is the widest quartz exposure seen by the writer. At some spots underground, however, the proximity of two or more zones of movement and percolation of solutions may be seen to have given rise to a mineralized width of as much as fifteen feet, of which vein quartz may account for only a couple of feet, the remaining width being altered wall rock. On the other hand, the vein over distances of several hundred feet along the strike is seen to be merely a narrow shear zone with little or no vein quartz present.

Decided curvatures, or "rolls", of important size are a notable structural feature of the vein. Up to the present time, three principal rolls have been outlined by drifting at various levels. The axes of these undulations are shown in plate 2. These curvatures, when projected upon a horizontal plane, are, of course, accentuated because of the gentleness of the dip. In the most northerly roll, (Roll "A", plate 2) post-mineral faulting has further exaggerated the curvature on the 840, 900, and 960 drifts. The origin of these structures is not known to the writer. Folding of the fissure and partial control of shearing by earlier jointing have both been suggested in this case as causes of deflections of strike.

Between the rolls the vein extends without major deviation in strike. Small variations in the course of the vein are present, but they appear to be without continuity or importance. Variations of dip as well as of strike are characteristic. Certain areas of the vein are found to differ in average dip from other, adjacent, areas. Deflections of strike and dip, combined with the effect of movement along the vein, have had 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-dip and southward relative to the footwall. This is shown by the offset of intermineralization cross-faults, and by the strike and appearance of striations on the vein walls at various points. Movement along the vein varied 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 come from one direction or another in the north-west quadrant. At one locality, however, striae would indicate strong southward strikeslip of the hanging-wall combined with small normal displacement. All in all, the net movement has very probably been a combination of thrust and southward strike slip of the hanging-wall over the footwall, as stated above.

As has been mentioned before, branching fractures stem from the main shear, and occur in both walls, especially the footwall. In one instance at least, namely, that of the footwall branch vein on the 1100 level (vein D, plate 2), the position of a minor vein has probably been controlled by curvature of the main vein. Southward movement of the hanging-wall against the buttress afforded by the nearby east-west striking section of the main vein possibly initiated 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 of little hindrance in mining, with several exceptions where offsets of between 50 and 100 feet have occurred. The faults may strike parallel or transverse to the strike of the vein, and displacement may be normal or reverse, more often the former. Dips are generally steep. Bending of the vein sometimes has accompanied the displacements. Small intermineralization faults show offset by the vein. The faults do not appear to have exerted any important influence in localizing mineral deposition.

IV MINERALIZATION

The quartz diorite wall rock of the vein frequently is intensely altered, although the width of the altered selvedge is ordinarily no wider than a few feet in either wall. Inclusions in the vein are mostly greatly altered and replaced by quartz. In an early stage of the alteration process, biotite, the dominant mafic of the country rock, is changed to green chlorite, and at a further stage the latter mineral is changed to muscovite with release of minute rutile needles which sometimes show knee twins. Associated with rutile is a mineral of prismatic, sometimes elongate, outline, high relief and birefringence, and of whitish color in reflected light. Extinction is apparently parallel to crystal outlines although not distinctly so because of dispersion effects. Probably this mineral is octahedrite or brookite. Pyrite is frequently concentrated near the site of a former biotite crystal. Arsenopyrite is present too, as euhedral crystals. Plagioclase feldspar is attacked by sericite at an early stage. Intense alteration obliterates the feldspar entirely, and its site becomes occupied by a felted mass of fine quartz and sericite, commonly with many patches of carbonate. Some albitization of plagioclase may have taken place. Hornblende alters in a way similar to biotite, while quartz appears largely uneffected, as does apatite. Calcite veinlets cut all of the other minerals.

Among the ore minerals within the quartz vein, pyrite is the earliest, and scheelite also is probably early. Fine chlorite has been deposited in early breccia zones within the quartz (fig. 4). 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 the ore minerals.

V INFLUENCE OF STRUCTURE ON LOCALIZATION OF ORE

A. Localization of quartz

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

A second type of area is that in which vein quartz of locally varying width forms a continuous sheet, with the exception of small pinched areas, over thousands of square feet. The widths of such continuous quartz bands may range from six inches to eight feet. Internal structure in these areas frequently is characterized by unsupported angular or tabular inclusions of altered wall rock in the quartz matrix.

Transitional between the two types of areas described above is a third type, which is distinguished by scattered and winding quartz stringers in the shattered and sheared country rock of the vein zone. In other places, sub-parallel narrow bands of quartz are separated by wider bands of altered country rock. Areas of this kind sometimes form gradations between areas of quartz and compression, or again, they may occur independently as small tracts within larger areas.

The relationship of the three types of areas is displayed in plate 3. The quartzless areas are areas of compression or bearing of wall against wall, by which the weight of the hanging-wall was mainly supported during the faulting and mineralization period. The quartz areas were formerly zones of looseness and brecciation through which hydrothermal solutions percolated and deposited their load when physical-chemical environment became favorable. Quartz areas were channelways for rising solutions, whereas compressional areas, because of their tight and gouged nature, did not permit the entry of solutions in any appreciable volume.

The compressional and quartz areas show a relation to strike and dip, as may be seen by reference to plate 3. Wide bodies of quartz are always of low dip. Quartz bodies in general occur in areas of flatter dip than do compressional areas. It should be noted that, although quartz bodies are found over a considerable range of dip, they are, where dip relations have been fully investigated, of flatter average dip than adjacent compressional areas. Differences of dip between adjacent areas, not absolute angles of dip, are important in this respect.

The influence of variations of strike is not so well marked as is the influence of dip variations. However, the occurrence of compressional areas on the north limbs of the two southernmost rolls (rolls B and C, plate 2) may be observed. Variations of dip and variations of strike mutually modify each other in their effect upon localization of quartz.

The factors which enter into the formation of tight and loose areas in faults, and the significance of these factors in the study of ore deposits, have been discussed by Newhouse (3). They are, namely, initial irregularity of the fracture surface, and direction and amount of fault movement in the vein. In the Independence vein, hanging-wall movement has been updip and southward. Those sections of the vein which strike more westerly or dip more steeply than adjacent sections should become compressional zones, and such is observed to be the case.

A noteworthy feature of the areal distribution of the compression areas is to be observed in plate 3. Underground observations mainly plus a conservative amount of extrapolation in some cases indicate that the compressional areas are isolated, while the quartz areas envelop the tight zones and are continuous, much as a river surrounds a group of islands. Such a relationship emphasizes the former function of the quartz areas as continuous channelways for rising hydrothermal solutions.

Areas of compression may arise through fault movement whose amount is insufficient to totally displace from each other the foot and hanging-wall companion curves of a given irregularity in the vein-fault. On the other hand, fault displacement may be far greater than the dimensions of the largest irregularity. In this case also, local compressional areas may conceivably be formed, but the two walls of a given compression 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, compression areas produced in either manner would, however, be areas of relatively steep dip.

The actual net amount of movement in the Independence vein is not known because of the absence of markers. The writer believes, however that the major compression areas are probably areas in which companion curves of the original vein fracture are partially in contact. Small pinched areas, on the other hand, probably are caused by irregularities of small dimensions compared with the amount of movement in the vein, and hence, they are the result of a fortuitous juxtaposition of foot and hanging-wall irregularities of similar attitude. It is believed that movement in the vein-fault of greater amount than the dimensions of the larger tight areas would have resulted in a different structure of the shear zone than that observed in the Independence mine. The rather close correspondence in strike and dip between the walls of the vein throughout the mine, combined with the unshattered nature of the walls adjacent to the immediate limits of the vein, would seem to indicate that original companion curves of the larger sort are partly in contact. Were this not so, sharp divergencies of the vein walls might be expected here and there... Of course, local, more or less gradual, divergencies of foot and hanging-wall are present, but are to be expected in view of the relative movement between the walls that has occurred from time to time, with resulting partial offset of companion curves. Moreover, intermineralization cross-faults offset by the vein commonly show only small displacements. To such faults, the offset parts of which could be definitely correlated, showed displacements of of about five feet. A few other faults, whose parts could

could be matched with less certainty, showed offsets of ten to fifteen feet.

B. Localization of gold

Gold ore shoots are in the main localized within 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 compressional areas of the vein will show a trace or more of gold as often as not. Transitional zones of altered rock traversed by irregular quartz stringers are frequently of sufficient tenor to form ore. The situation is that of a fracture zone widely permeated with gold in small amount, but with the commercial ore shoots almost entirely limited to areas of refractured quartz which form the major parts of the quartz areas themselves. In general, quartz is ore, with some notable exceptions. Comparison of plates 1 and 3, which show, respectively, extent of ore shoots (stoped areas) and extent of quartz areas, will bear out this statement with the reservation that ore still stands unmined in certain recently opened ground. This fact of the main localization of gold in quartz is, of course, a common phenomonon.

Within an oreshoot, the assay values of various samples of ore may vary widely. A sample cut at one spot may assay 1 oz. of gold, for instance, while another sample cut three feet away from the first may assay 0.1 oz. or less. Channel sampling can indicate the presence of an oreshoot 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 in the question of what is to 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 which occur interspersed with the high ones. Mining results have shown this to be justified. At the present time, the vagaries of the distribution of gold within the quartz of an oreshoot remain unexplained. Where ore is of extremely high grade, assays along the vein may all be high, but here too the variation from sample to sample may be great. Some uniformity among assay values is achieved in barren or semi-barren ground, where all samples may assay low. In addition to considerations of assay value, quartz, in order to be mined, must, of course, be of reasonable width and continuity.

The immediate problem is to explain the position of oreshoots and barren shoots as defined above. In certain occurrences of barren quartz and ore, where the position of ore appears to be related to vein strike and dip, the problem seems answerable, while for other occurrences no solution presents itself.

From an examination of thin sections of vein quartz it becomes apparent that the rise and deposition of gold in the vein has been 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 replace the quartz. High-grade quartz is intimately fractured along closely spaced micro-brecciation zones. A single thin section of such ore may be traversed by two or three such zones of micro-brecciation.

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

Rather to be explained than the occurrence of gold with quartz is the existence of certain sections of quartz vein which are lacking in an appreciable content of gold. Those sections of vein which are characterized by exceptionally large thicknesses of quartz have been, to the present time, of such low tenor as to be not independently minable as ore. These thickest quartz bodies are those of lowest dip, as has been noted already. Three such thick bodies of low-grade quartz are designated as areas 1, 2, and 3 in plate 1. Up-dip from these thick lenses, and probably down-dip as well, the quartz vein becomes thinner as the local dip increases, and here the quartz becomes enriched in gold.

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

An assumed horizontal thrust of the hanging-wall block against the top of the quartz vein could be considered as 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 second force component is normal to the vein and tends to press the vein walls together. In the flatter dipping sections of the vein, the first component is great and the second component small, while in sections of vein of steeper dip, the first force component is diminished and the second is increased. As the hanging-wall moves up-dip relative to the footwall, shear and brecciation ensue within the vein. In the flattish dipping areas of thick quartz, shear movement which is initiated 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 vein, on the other hand, are subjected to greater normal compressive force, which would tend to cause a more permeative fracturing of the quartz rather than to cause the localization of fracture to a relatively narrow zone within the vein. This hypothetical relationship is illustrated in figure 3. Some such mechanism has apparently operated during the enrichment of the quartz above area 1 in plate 1. Sparse gold values in the thick vein along the drift are limited to the upper one-fourth of the vein cross-section, causing the vein as a whole to assay low. Up-dip from the thickest section of the lens an ore-shoot occurs as assays across the vein increase markedly. The examination of four thin sections of quartz from the wide part of the vein reveals an absence of micro-brecciation.

In areas 2 and 3, a similar manner of late movement should be discovered by detailed examination and sampling across the vein. Concentration of late movement along a gougy zone on the hanging wall of the thick quartz vein might effectively prevent any important refracturing of the quartz. At any rate, the writer considers that the areas lying immediately down-dip from areas 1 and 2 are very likely spots for the occurrence of ore.

A somewhat different situation exists in area 4 (plate 1). Here, a gently-dipping lens of quartz varying from one to three feet in thickness is almost barren of gold over a considerable area. A narrow shear 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 further up the dip, where the dip of the vein begins to steepen, the hanging-wall shear converges with the vein. This small shear has apparently acted as a "by-pass" along which late movement has occurred in preference to occurring within the quartz vein itself. At the upper edge of the barren lens, where by-pass shear and vein converge and the vein dip increases, ore occurred but has been stoped. Concentration of late movement along the small shear in the hanging-wall of the low-dipping quartz lens has deprived the body of quartz of the fracturing necessary to its enrichment by gold-bearing solutions. A couple of thin sections of the barren quartz show but slight late disturbance. Figure 2 illustrated diagrammatically the relations of vein and ore to the by-pass shear.

The results of an attempt to correlate evidence of late movement in thin sections with the grade of ore at the places where the specimens were taken are, for the most part, what would have been anticipated from the larger structural relations observed. Thin sections of high-grade ore almost always show micro-brecciation, usually intense but occasionally weak.

Sections of ore of moderate grade usually show microbrecciation of strong or of weak intensity; sometimes it is lacking. Sections of material from the thick barren lenses of quartz lack the cataclastic texture entirely, or may show infrequently a weak micro-shear. The correlation, then, is imperfect, but nevertheless it exists definitely in a qualitative way.

The section of quartz vein exposed along the 1100 South drift (between points E and F, plate 2) is of peculiar character in that it is composed of alternate dark and light bands across its width. The light bands are of white quartz; the dark bands in thin section are seen to be caused by introduction of chlorite into quartz along what are apparently broad, parallel, brecciation zones, presumably of early origin. Figure 4 is a photograph of the occurrence. This length of vein is but lightly mineralized with gold. Several high assays occur bunched together but the section as a whole is not ore. From the presently available facts the writer does not know of an explanation for this scanty mineralization persisting over such a considerable length of quartz vein. This particular occurrence is an apparently important exception to the generalization developed in preceding pages, namely, that continuous areas of quartz are minable as ore, exclusive of thick bodies of low dip. Future development will probably provide data upon which some explanation may be based.

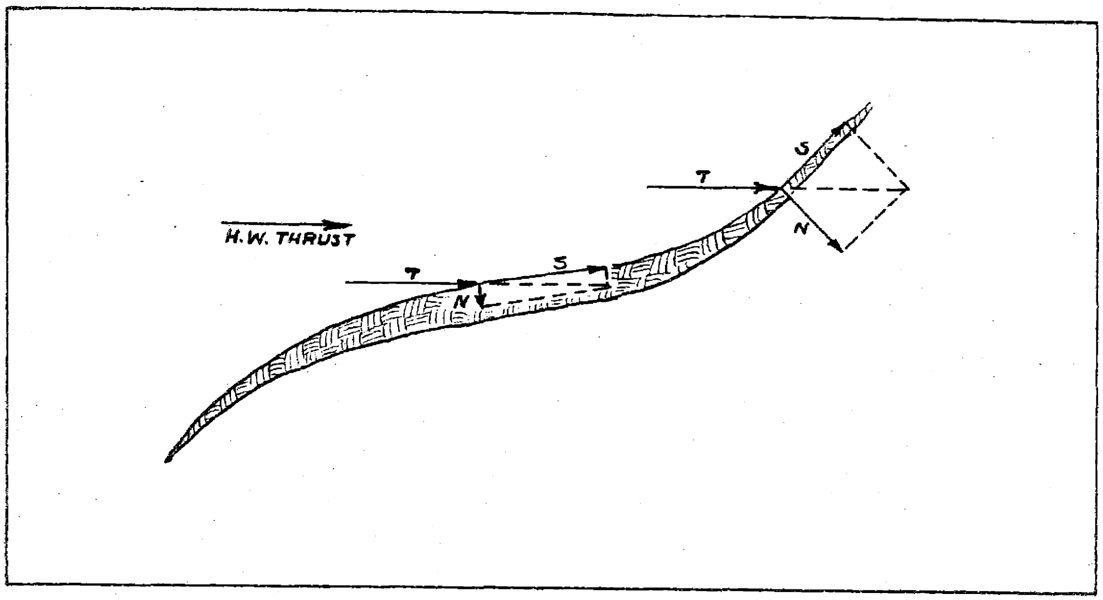


Figure 1. Diagrammatic sketch showing disposition of the components of a horizontal thrust on a vein of variable dip.

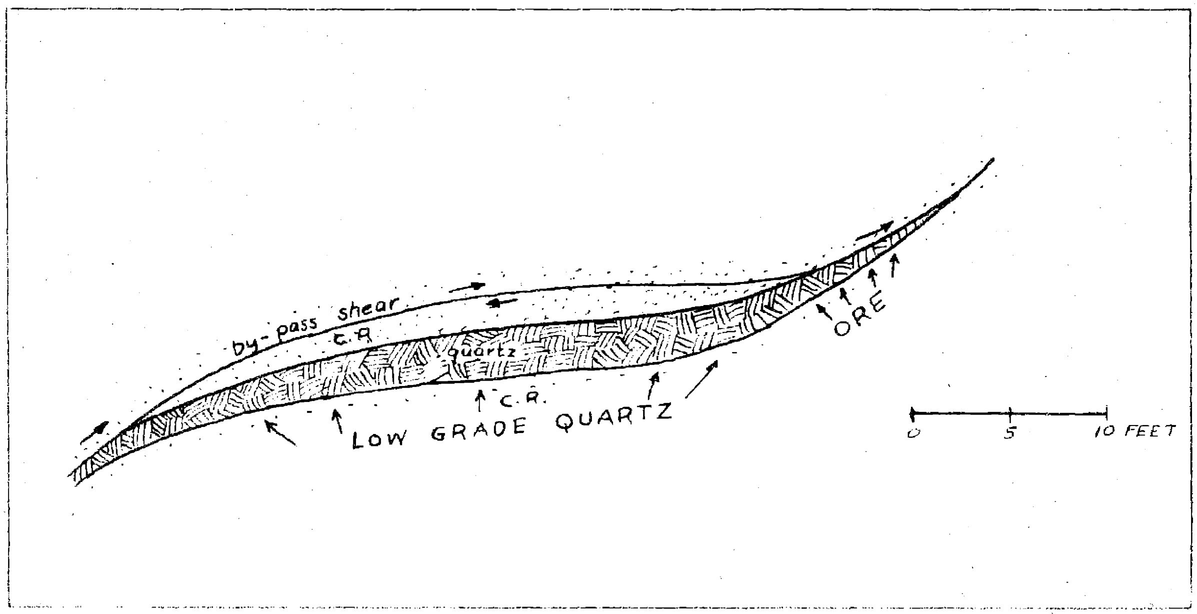


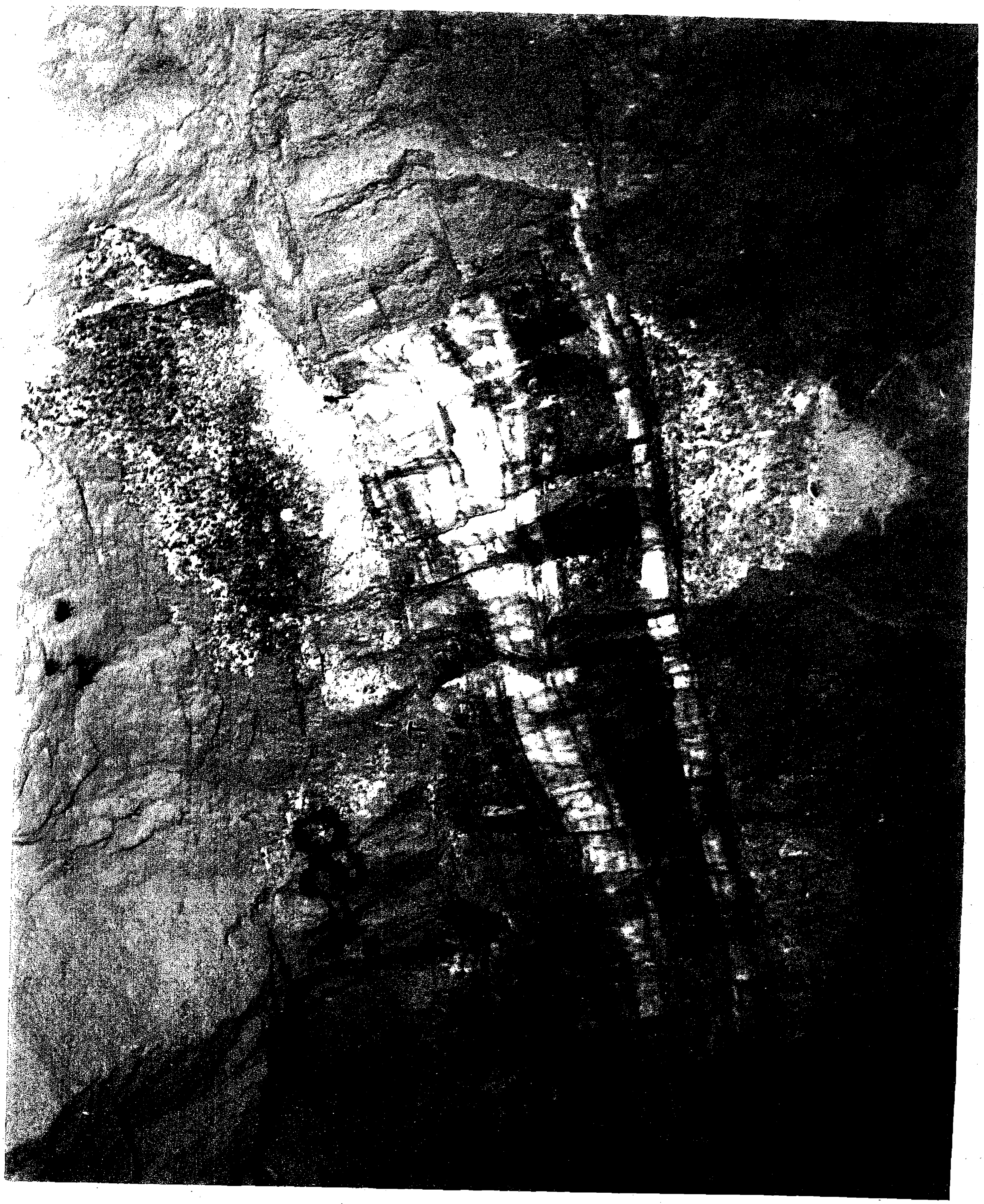
Figure 2. Diagrammatic sketch showing relation of by-pass shear to quartz vein.

Figure 3. Sheared, high-grade, quartz vein, 1200 level north. T marks the hanging-wall of the quartz vein.

H. G. Ferguson ((4)p.54), summarizing the characteristics of the oreshoots of veins following reverse faults in the Alleghany district, California, says that, in several cases, the thickest lenses of quartz are not productive. In the Sixteen to One mine, quartz in the productive portions is thicker than the average, but the thickest swells in quartz are non-productive. He describes the productive part of Eldorado mine as probably of steeper dip than the average. At the mine under discussion in the present paper, the steepest dipping sections are barren of quartz, the flattest areas show thick quartz but little gold, and the areas of intermediate dip carry less quartz but more gold. This generalization is subject to modifications due to the influence of changes of strike and to other factors which are described.

In summarizing the causes of localization of oreshoots in the Independence mine, it may be said that quartz areas have been loci of deposition of late minerals because of the mode of fracture of the quartz. Thick quartz lenses have not undergone late fracturing to any considerable extent because of their low dip, and hence these parts of the vein remain unenriched. The relative barrenness of another quartz area, of different type, remains unexplained at present. Adjacent to thick lenses, where local dip increases, permeative fracturing of the quartz and enrichment have occurred.

Figure 4. Banded quartz vein, 1100 level south near foot of raise no. 10. The dark bands are caused by introduction of chlorite into quartz along parallel zones of brecciation. T marks the top of the vein.



VI INTERNAL STRUCTURE OF THE VEIN

The most noteworthy feature of the internal structure of the Independence vein is the extremely frequent occurrence of unsupported inclusions of altered wall rock in the quartz. These inclusions may be angular, large or small, or they may be long and slender, lying about parallel to the vein walls. The country rock of which the inclusions are constituted may appear slightly altered, with granitic texture clearly recognizable in the hand specimen, or as highly altered material from which dark silicates have 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.

Long, slender, inclusions are here interpreted as remnants of sheared, altered, and partially replaced country rock which remained after most of the surrounding sheared material had been entirely replaced by quartz (figure 5,6, and 7). Angular inclusions are relicts of irregularly brecciated country rock partly replaced by quartz (figures 7 through 10). The long inclusions in quartz may be termed a "replaced shear" structure, while the angular inclusions in quartz may be called a "replaced breccia" structure. ((5), p.412).

In thin section, small breccia fragments in the vein are seen to be almost wholly replaced by quartz. The shapes of the fragments may be rounded, angular, or irregular. Within their boundaries occur concentrations of sericite, mostly, with some carbonate, pyrite, or chlorite, usually. Quartz, which constitutes the bulk of such an inclusion, is of variable grain size, but always of smaller grain size than the surrounding quartz matrix. Occasionally,a euhedral or subhedral crystal of quartz may be 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 stage of the replacement process, in which recrystallization of small grains has tended toward the production of the typical coarse texture of the vein.

Some of the narrow quartz veinlets which occasionally are to be observed cutting the altered rock of hanging or footwall of the vein appear to be of replacement origin, largely (figure 11). Megascopically, these veinlets are sometimes characterized by the presence of included delicate septa of wall rock. A couple of thin sections cut across the contact of one of these veinlets and its wall rock reveal 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 with the plagioclase tiny relicts of unreplaced feldspar. The quartz projections into the feldspar may or may not be optically continuous. Sericite shreds inherited from the altered feldspar are sometimes contained, apparently uneffected, 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 prevailing texture is the usual coarse, hypidiomorphic granular one. In one section, a couple of unreplaced relicts of sericitized plagioclase remain completely enveloped by the quartz veinlet. The contact is, in detail, irregular and in some places poorly defined.

Origin of these quartz veinlets would appear to be about as follows: fracturing along one surface or several parallel, closely spaced, surfaces and introduction of quartz-bearing solutions which replaced the wall rock immediately adjoining the cracks (6). Possibly a repetition of the slight movement may have taken place, especially where such veinlets have widths of more than an inch or two. The replacing quartz at first assumed the form of extremely irregular masses containing inclusions. Recrystallization ensued with expulsion of inclusions and the formation of regularly bounded quartz anhedra of increased size. Continued enlargement of indivual grains with entire removal of sericitic inclusions from the system produces the typical hypidiomorphic granular texture of the quartz vein.

Figure 5. Long, slender inclusion of altered wall rock in quartz, 1200 level north. The arrow points to the inclusion. T marks the top of the vein.

Figure 6. Elongate inclusions in quartz attributed to shearing followed by partial replacement by quartz. The large inclusion, marked A, is of altered country rock, while the others are mostly dark, medium-grained quartz somewhat stained by limonite.

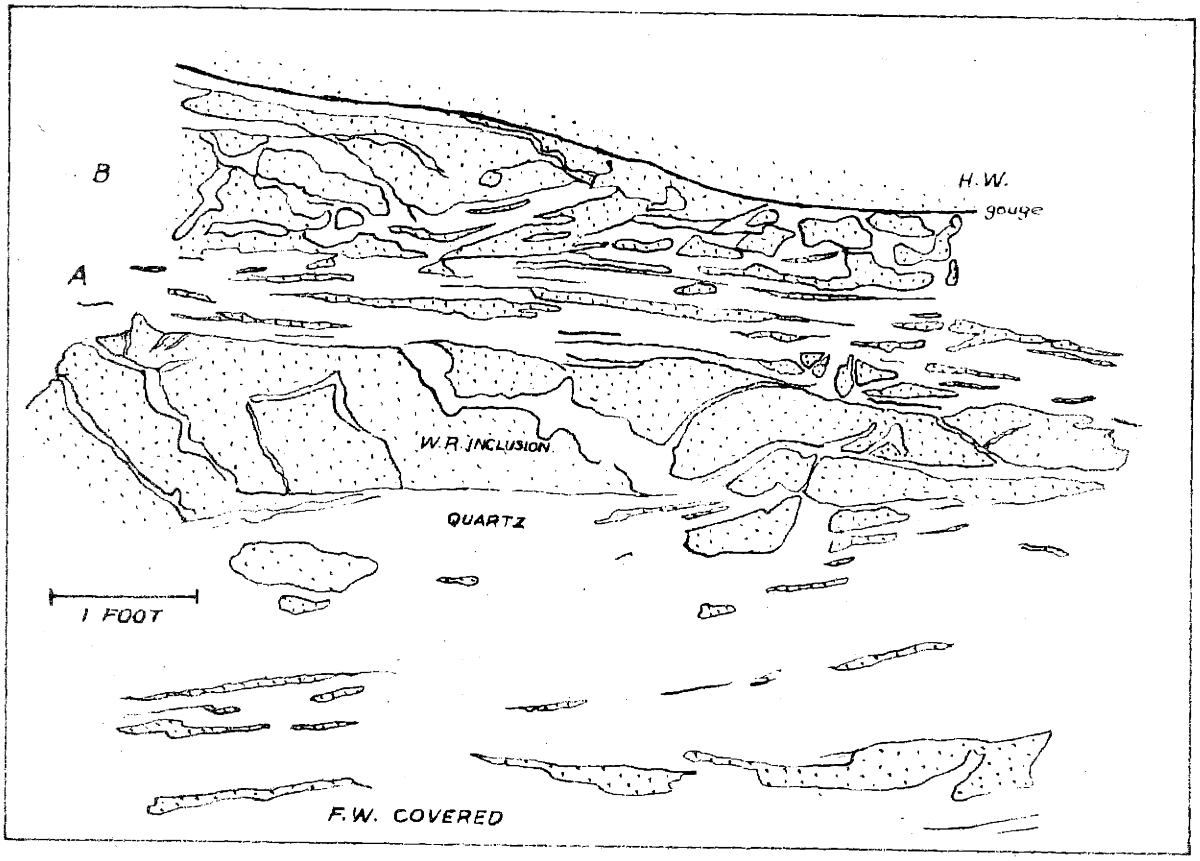


Figure 7. Diagrammatic sketch of vein cross-section, 1100 level south near foot of no. 12 raise. The stippled areas are country rock and the blank areas are quartz. The part designated by letter A is a replaced shear structure. B designates a replaced breccia structure.

Figure 8. A wall rock breccia partly replaced by quartz.

Figure 9. A large wall rock breccia fragment suspended in quartz, 1100 south drift. Other, smaller, fragments may be seen in the quartz. T marks the top of the vein.

Figure 10. A closer view of the suspended block shown in Fig. 9.

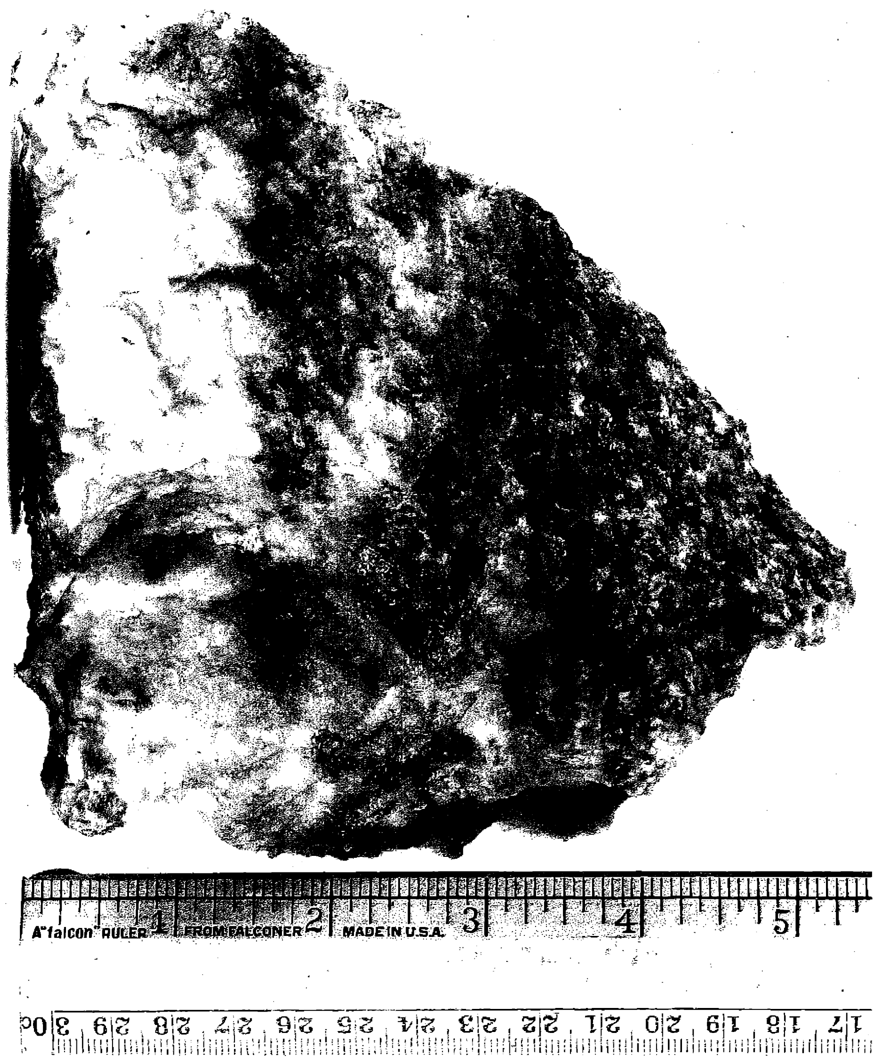


Figure 11. Irregular veinlets of quartz replacing country rock.

VII CONCLUSION

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

(1) Original fracturing and movement along the vein-fault with initiation of subsidiary breaks and development of tight and loose areas in the vein-fault, followed closely by the rise of hydrothermal solutions which caused alteration of the country rock along the vein.

(2) Repetition of movement with rise of solutions bearing silica. These solutions were restricted mostly to the loosely brecciated and sheared channel-ways which now appear as the quartz areas of the vein. The solutions effected replacement of the shattered and sheared wall rock and filling of small open spaces. A number of repetitions of this process occurred.

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

VIII ACKNOWLEDGEMENTS

The observations upon which this study is based were made by the writer at the Independence Mine, Alaska, 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 are now inaccessible for various reasons, were supplied by A. G. Dodson, mine foreman. G. H. Gilson and N. E. Nelson, mining engineers, have very kindly informed the writer of certain pertinent developments which occurred after his departure from the mine at the end of the summer. Information on the larger geological features of the Willow Creek district was derived mostly from bulletins of the United States Geological Survey written by Stephen R. Capps and James C. Ray. Underground photographs were taken by Mr. Web Harrison of Seattle. Professor W. H. Newhouse of the Massachusetts Institute of Technology has kindly rendered valuable criticism and aid throughout the preparation of the thesis.

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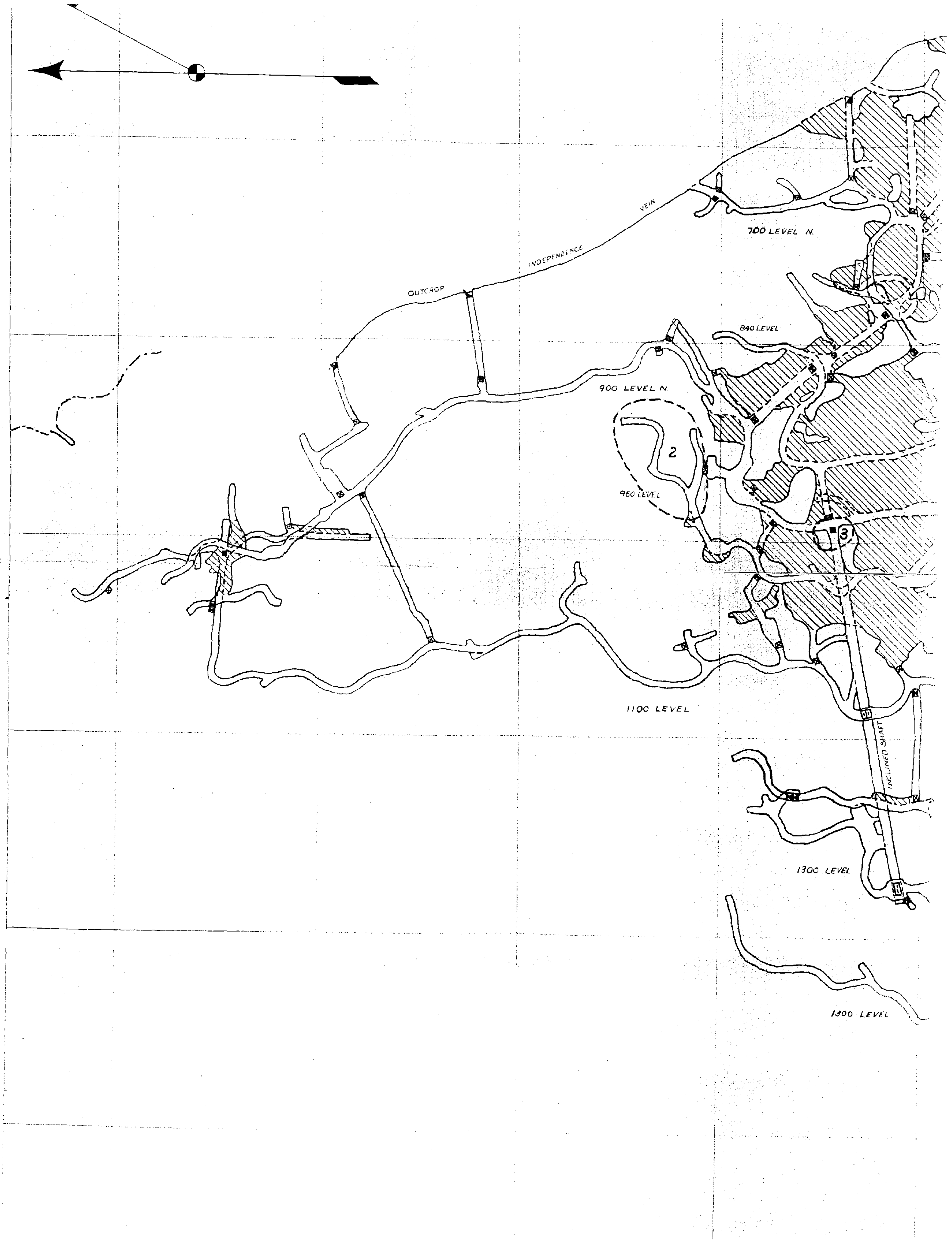
PLATE 1



OUTCROP
INDEPENDENCE
VEIN
700 LEVEL N.
840 LEVEL
900 LEVEL N.
2
960 LEVEL
3
1100 LEVEL
INCLINED SHAFT
1300 LEVEL
1300 LEVEL

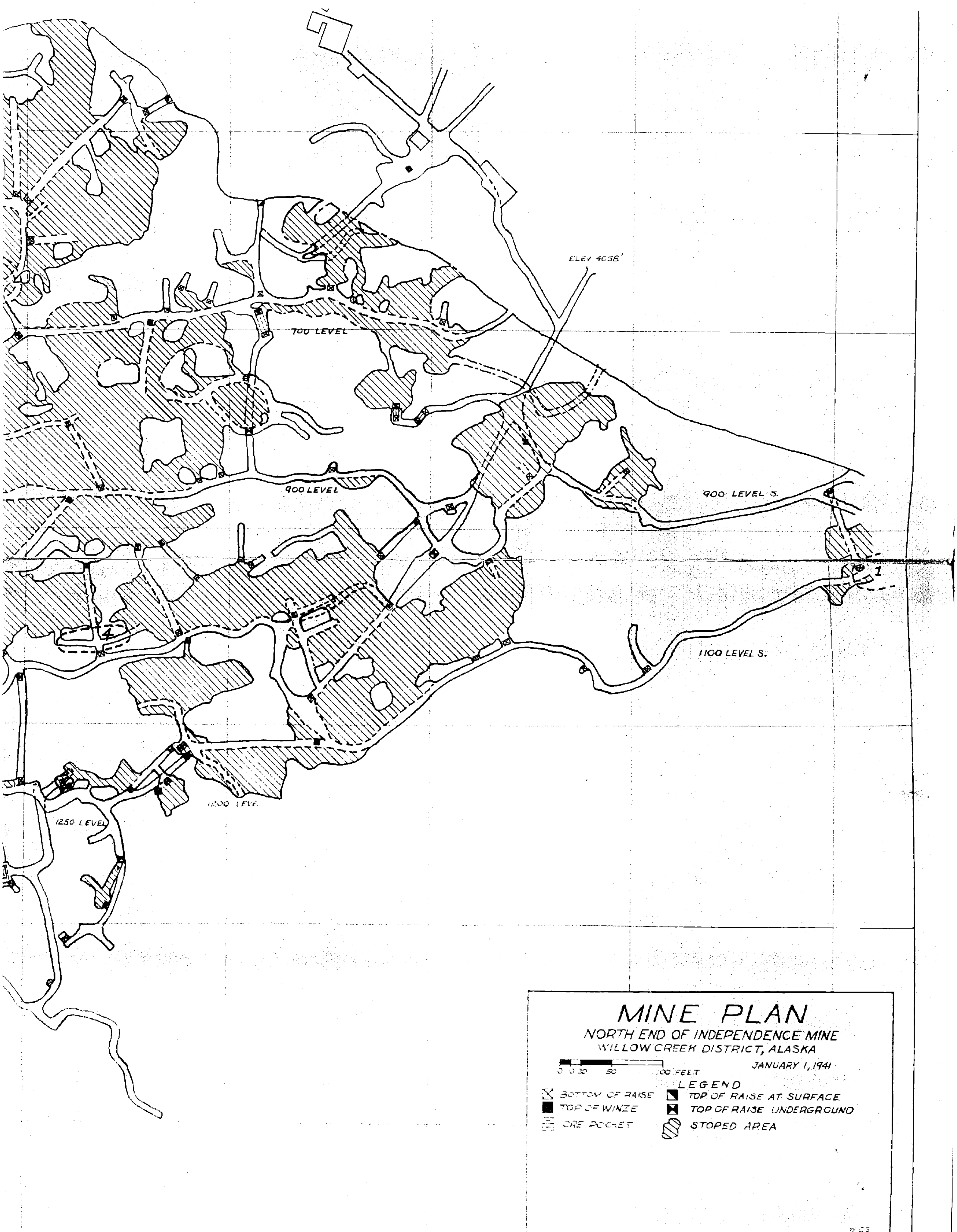
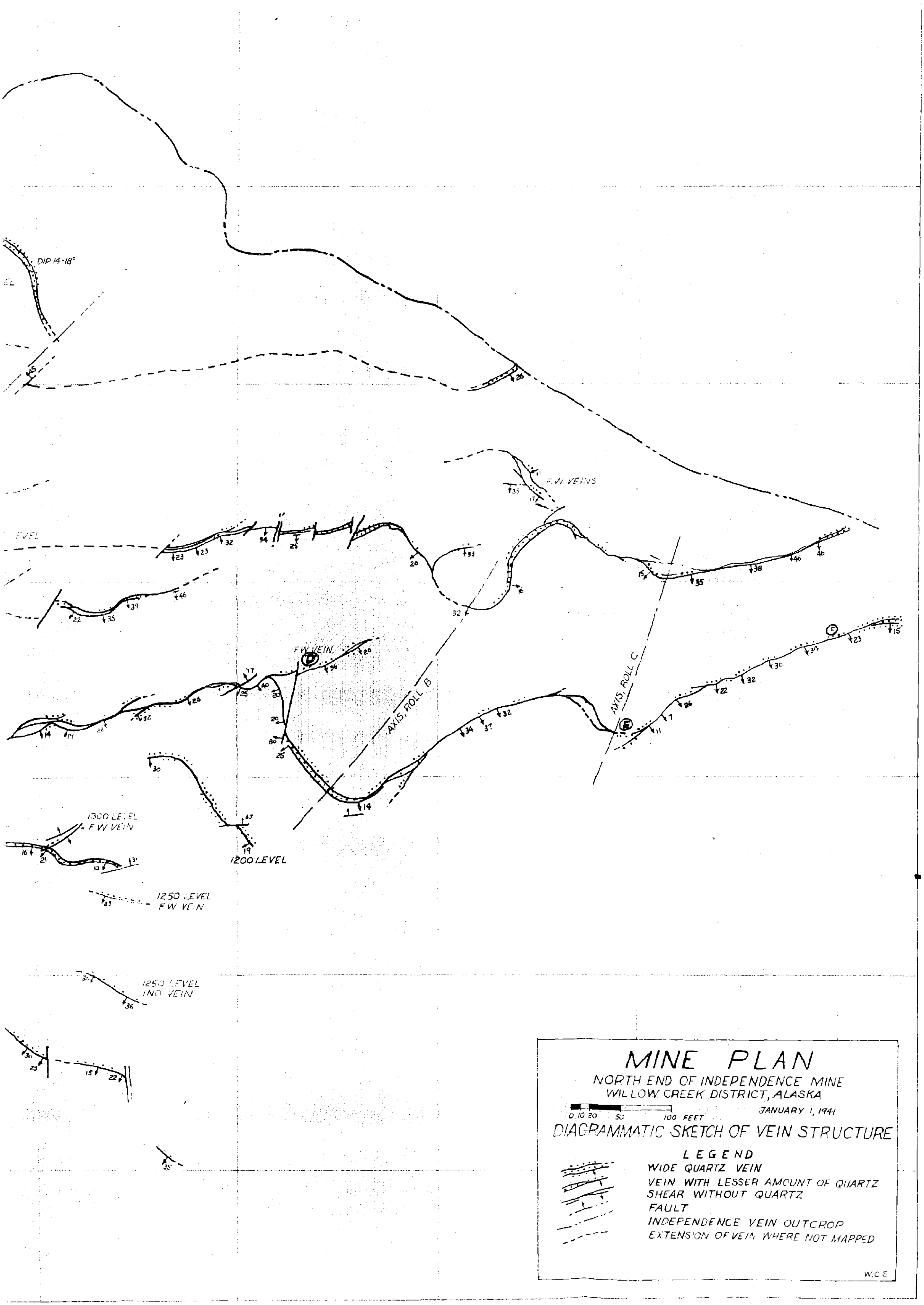

ELEV 4058'
700 LEVEL
900 LEVEL
900 LEVEL S.
1100 LEVEL S.
1200 LEVEL
1250 LEVEL
1
4
MINE PLAN
NORTH END OF INDEPENDENCE MINE
WILLOW CREEK DISTRICT, ALASKA
JANUARY 1, 1941
0 10 20 50 100 FEET
LEGEND
BOTTOM OF RAISE
TOP OF RAISE AT SURFACE
TOP OF WINZE
TOP OF RAISE UNDERGROUND
ORE POCKET
STOPED AREA

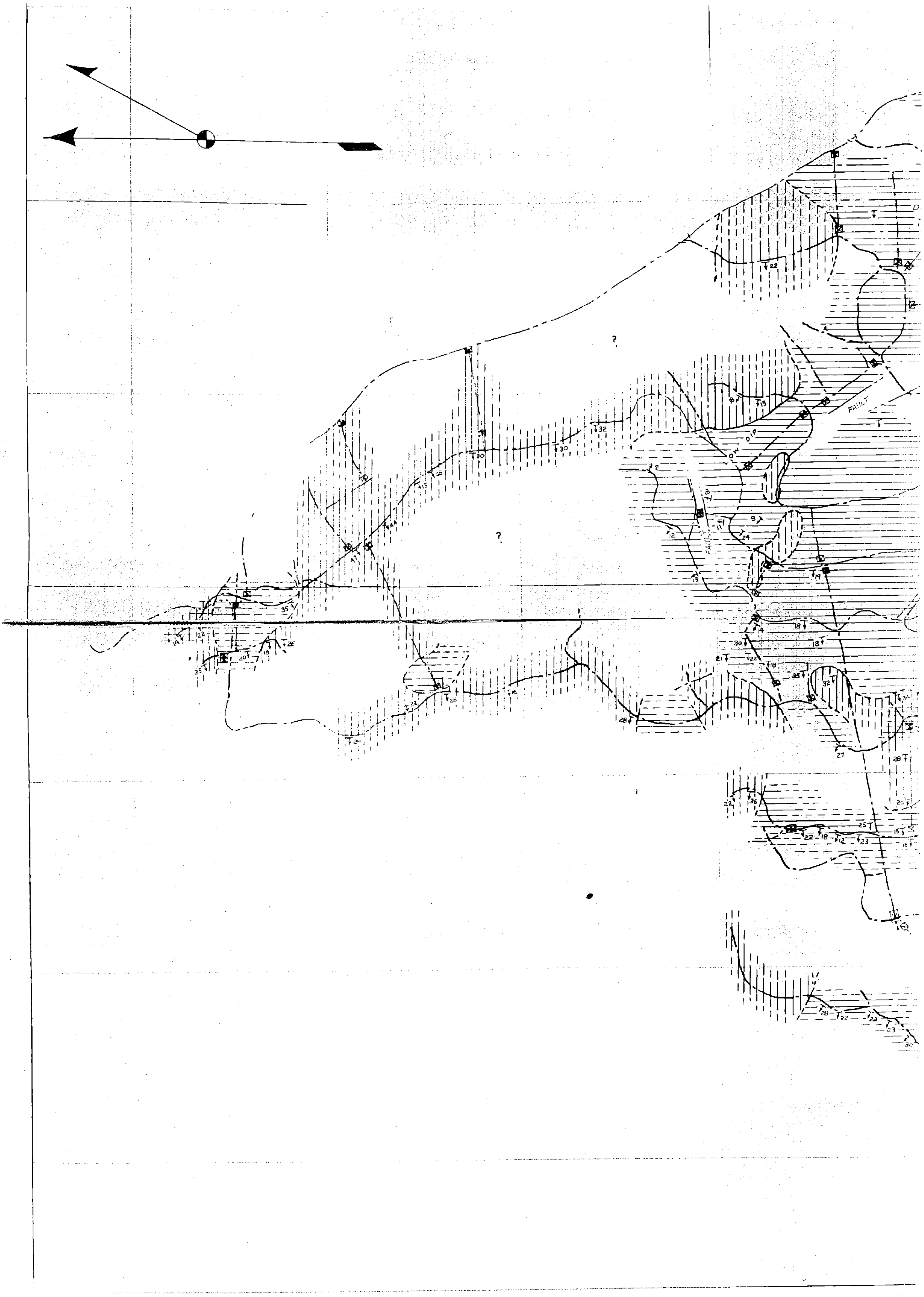
PLATE 2

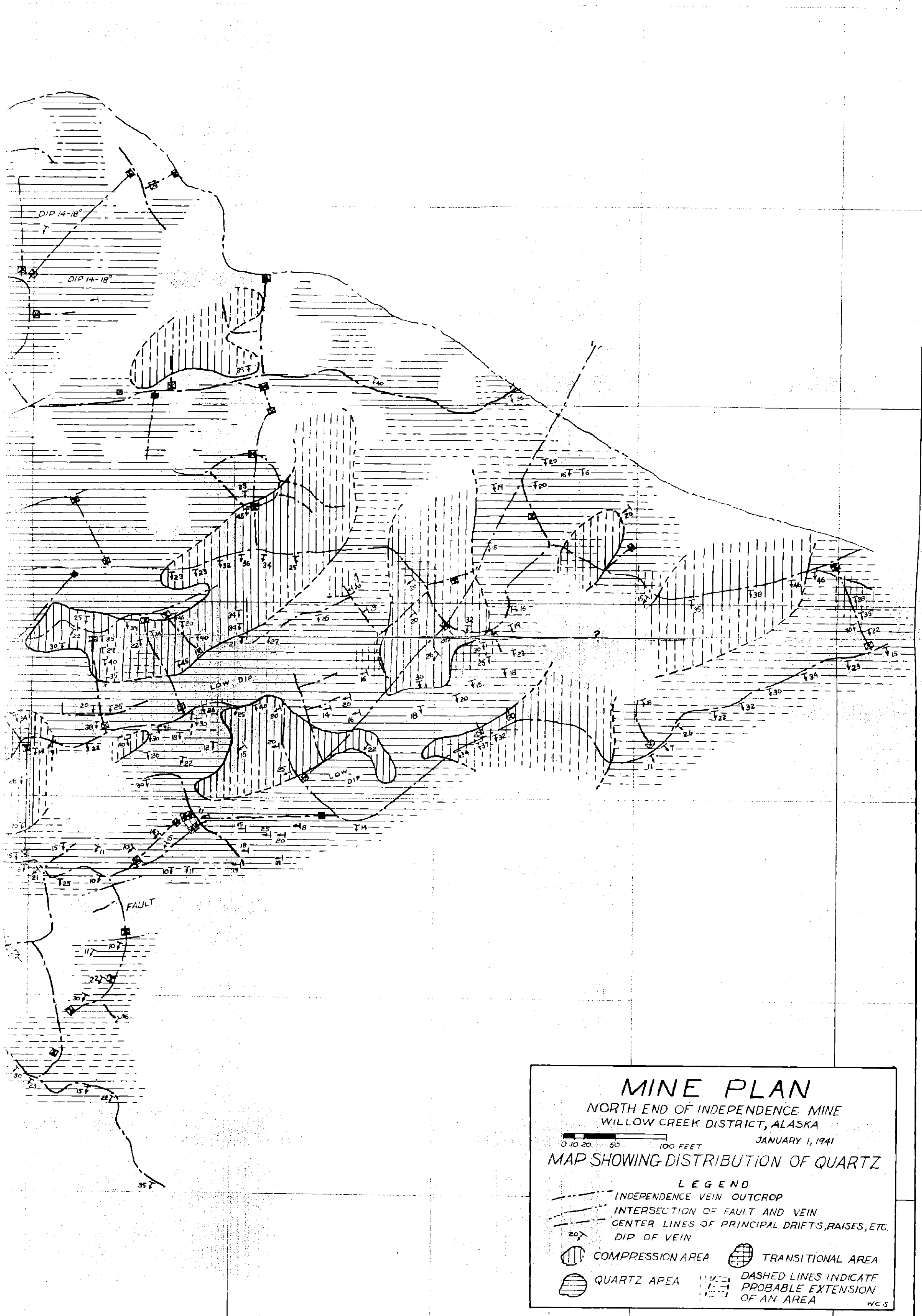
700 LEVEL
H.W. VEIN
840 LEVEL
900 LEVEL
F.W. VEIN
960 LEVEL
AXIS, ROLL A
1100 LEVEL
1250 LEVEL
1300 LEVEL
F.W. VEINS
1300 LEVEL
IND. VEIN



DIP 14-18°
F.W. VEINS
F.W. VEIN
AXIS, ROLL B
AXIS, ROLL C
1300 LEVEL
F.W. VEIN
1200 LEVEL
1250 LEVEL
F.W. VEIN
1250 LEVEL
IND. VEIN
MINE PLAN
NORTH END OF INDEPENDENCE MINE
WILLOW CREEK DISTRICT, ALASKA
0 10 20 50 100 FEET
JANUARY 1, 1941
DIAGRAMMATIC SKETCH OF VEIN STRUCTURE
LEGEND
WIDE QUARTZ VEIN
VEIN WITH LESSER AMOUNT OF QUARTZ
SHEAR WITHOUT QUARTZ
FAULT
INDEPENDENCE VEIN OUTCROP
EXTENSION OF VEIN WHERE NOT MAPPED
W.C.S.

PLATE 3


FAULT
LOW DIP
FAULT


MINE PLAN
NORTH END OF INDEPENDENCE MINE
WILLOW CREEK DISTRICT, ALASKA
0 10 20 50 100 FEET
JANUARY 1, 1941
MAP SHOWING DISTRIBUTION OF QUARTZ
LEGEND
INDEPENDENCE VEIN OUTCROP
INTERSECTION OF FAULT AND VEIN
CENTER LINES OF PRINCIPAL DRIFTS, RAISES, ETC.
DIP OF VEIN
COMPRESSION AREA
TRANSITIONAL AREA
QUARTZ AREA
DASHED LINES INDICATE PROBABLE EXTENSION OF AN AREA
W.C.S.
DIP 14-18°
DIP 14-18°
LOW DIP
LOW DIP
FAULT