UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
W. E. WRATHER, Director

PRELIMINARY REPORT ON THE GEOLOGY AND ORE DEPOSITS OF THE WILLOW CREEK MINING DISTRICT, SOUTHERN ALASKA

by

Richard G. Ray, 1920-

This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

CONTENTS

ILLUSTRATIONS

ABSTRACT

The Willow Creek mining district is a small but important lode gold mining district along the southern border of the Talkeetna Mountains in southern Alaska. To date the district has produced about 5 percent of Alaska's lode gold output.

Productive gold quartz veins occupy early shear zones in the southern margin of the Talkeetna batholith, largely quartz diorite in this area. The quartz diorite is flanked on the southwest by mica schist and on the southeast by sedimentary rocks. Dikes of lamprophyre, diabase, and aplite-pegmatite cut especially the quartz diorite. Lamprophyre dikes particularly fall into a recognizable pattern and may be useful in determining quantitative displacements of post-ore faults These dikes have been mapped in considerable detail. The major post-ore faults, which define a second set of shear zones, have displaced productive veins as much as 600 feet.

An older group of veins, commonly containing molybdenite, chalcopyrite, and sometimes stibnite, rarely gold, follow strong southwest-dipping joints. These older veins are nonproductive.

Cavity filling was prominent in the formation of productive veins. Continued movement in the planes of the shear zones opened new cavities where additional quartz was deposited. Bodies of quartz several feet thick formed in places, but these do not persist for great distances along the shear zones. Quartz bands characteristically swell and pinch, and pass into barren parts of shear zones. The shear zones themselves, however, are notably persistent but are everywhere limited by major post-ore faults.

The ore is essentially a free-milling gold quartz ore containing small amounts of sulfides and tellurides. The gold is unusually fine grained. It occurs as small isolated flakes or as blebs strung out in quartz; sometimes it forms as fillings around earlier euhedral quartz crystals; but most commonly it is directly associated with sulfides and tellurides. The gold is especially closely associated with the telluride nagyagite, and where nagyagite has been observed, the tenor of the ore is high. Tellurides have been reported previously but are identified here for the first time. Gold was deposited where favorable conditions existed, particularly at the intersections of smaller veins with the main veins where the quartz host was perhaps more susceptible to fracturing.

Wall rock alteration has been intense adjacent to productive quartz veins but seldom extends more than 10 to 12 inches beyond the quartz filling. This hydrothermal activity has destroyed hornblende, biotite, plagioclase, magnetite, and chlorite, and has resulted in the formation of sericite, carbonate, sulfides, and quartz(?). It is a kind of alteration typically accompanying veins described as mesothermal.

All mines in the Willow Creek district are small, and most minable veins have been exploited only to shallow depths. Yet the veins in this district are similar mineralogically and structurally to veins of other districts where mining has been carried out for several thousand feet in depth. Larger scale operations are needed to exploit the Willow Creek type of veins most successfully. The geologic setting of the Willow Creek veins is favorable to successful lode mining, but this is temporarily overbalanced by unfavorable economic conditions.

INTRODUCTION

The Willow Creek gold mining district is an irregularly shaped area of about 50 square miles lying east of the railroad belt in southern Alaska (fig. 1). The center of the district is 20 miles by dirt road from the town of Wasilla, on the main line of the Alaska railroad, and 25 miles from Palmer, on a spur of the Alaska railroad. Both highway and rail connections link Palmer with Anchorage, 50 miles to the south.

The mining district is within an area that was intensely glaciated, and it now presents features of typical "biscuit board" topography. Steep-walled cirques and hanging valleys separated by sharp arêtes are characteristic. The recorded glaciation is of the alpine type as attested by the jagged, saw-tooth ridges which give most of the district a rugged and impressive appearance. The intense glaciation has sculptured peaks which attain 6,000 feet in places. Relief of 2,000 feet within 1 mile is not uncommon. The steep cirque and valley walls are usually mantled near their bases by wide talus slopes commonly containing blocks of quartz diorite 10 to 15 feet across. Valley floors were originally covered with glacial debris, but these have almost everywhere been modified somewhat by postglacial drainage. Postglacial stream gravels have not developed to any extent, however, and stream beds are typically strewn with large boulders.

Glaciation has destroyed the possibility of commercial placers for the most part and has made prospecting for lodes somewhat more difficult. The best rock exposures are high on the valley walls, and as a consequence many mine openings occur in these more easily prospected, but difficultly accessible areas.

In general the summers within the mining district are rather wet and cool. From the end of May through September temperatures between 40° and 50° F. are common. The seasons are not predictable, however. The summer of 1948 was cool and wet whereas the summer of 1950 was unusually warm and dry. The normal snowfall is reported to be between 4 and 5 feet. Between 16 and 20 feet of snow fell during the winter of 1948-1949, but this was an exceptionally severe season. Although most of the snow falls during the winter months light snowfalls can be expected at any time throughout the year. Heavy winter snowfalls together with the rugged character of the terrain are responsible for numerous snowslides which not only increase the difficulty of maintaining roads during the winter months but are a constant hazard to the mining camps, many of which have suffered extensive damage in the past.

The mining district lies entirely above timber line. Some small willows grow in the upper reaches of the Little Susitna River, but most areas are barren of trees, and timber for mining purposes must be shipped in.

Between the discovery of lode gold in 1906 and the present, a number of investigations have been made by the Geological Survey in the Willow Creek district. The more important investigations were by S. R. Capps 1/ in 1913 and by J. C. Ray 2/

1/ Capps, S. R. 1915, The Willow Creek district, Alaska: U. S. Geol. Survey Bull. 607, 86 pp.
2/ Ray, J. C., 1933, The Willow Creek gold lode district, Alaska: U. S. Geol. Survey Bull. 849-C, pp. 165-229.

in 1931. Although these workers contributed a great deal to the geologic knowledge of the mining district, Capps mapped the area only in a general way at a time when the district was just opening up, and J. C. Ray appears to have confined his attention largely to underground studies. Between 1948 and 1951 R. G. Ray conducted a more detailed investigation of the area. He was assisted during the season of 1950 by B. W. Wilson. A comprehensive report is now in preparation, based on field and laboratory studies. In order to make available immediately the pertinent results of this recent study the following short preliminary report and geologic map are issued. Photographic illustrations, detailed mine maps, and discussions of individual mines have of necessity been omitted here.

GENERAL GEOLOGY

General Geologic Features

The Willow Creek mining district is a small marginal segment along the south front of the Talkeetna batholith in southern Alaska. The batholith is roughly 1,500 square miles in extent and is believed to have been emplaced in late Mesozoic time. Older reconnaissance surveys have revealed several rock types within the Talkeetna batholith, but in the Willow Creek mining district the igneous rock is largely quartz diorite. This intrusive mass is bordered on the southwest by low-grade mica schist. To the southeast, steeply tilted sedimentary rocks rest unconformably upon the batholith front.

Fracturing in the batholith margin provided structural channelways for the introduction of gold quartz veins and associated lamprophyre, diabase, aplite, and pegmatite dikes. All these features were disrupted by major faulting which took place late in the tectonic history of the intrusive mass.

Intrusive Rocks

Quartz diorite

The Willow Creek mining district is underlain predominantly by quartz diorite although small masses of granite and gabbro are present locally. Most of the rocks exhibit primary flow structures and have a gneissoid appearance.

The quartz diorite ranges from fine to medium grained; the finer grained phase is generally restricted to the southern border of the igneous mass. Plagioclase, quartz, biotite, hornblende are the chief minerals with microcline, orthoclase, sphene, apatite, zircon, and magnetite comprising the accessory constituents. The plagioclase ranges from about 32 to 48 percent anorthite. In some areas hornblende is more prominent magascopically and appears to be the most abundant mafic mineral, whereas in other areas biotite is more conspicuous to the naked eye and seemingly predominates over hornblende. No uniform distribution of one or the other of these types could be mapped, although, in a general way, the more noticeably biotitic phase occupies an area nearer the southern border of the intrusive mass, and hornblende is more prominent magascopically in the northern part of the area mapped. Where hornblende is more prominent, it is generally coarser grained than the associated biotite, and vice versa.

The quartz and plagioclase content of the quartz diorite is roughly uniform throughout the district. The feldspar tends to become more basic and more strong zoned towards the center of the igneous mass, however.

Along the southern border of the igneous mass the quartz diorite is finer grained and more strongly foliated than that which underlies most of the mining district. Mineralogically, the finer grained border phase is similar to the normal medium-grained quartz diorite to the north except that micrometric analyses show hornblende to be present in slight excess over biotite. So far as can be determined from field observations the finer grained phase and the normal quartz diorite are parts of the same intrusive sequence. The finer grain-size reflects the cooler environment in which these rocks crystallized.

Gabbro

In the southeast part of the mining district the country rock is a greenish-black, medium-grained hornblende gabbro. This rock appears to grade northward into the normal quartz diorite although more detailed study of the area between these two rock types is needed to clarify their relationships. The rock is composed essentially of hornblende and plagioclase feldspar. Pyroxene is notably absent in specimens collected by the writer although in a specimen collected by Capps, presumably from this same area, pyroxene is abundant. Apatite, sphene, and magnetite are the accessory minerals. Calcite is present mainly in a network of secondary carbonate veinlets that cut the gabbro. In a few places hornblende has altered to chlorite.

Granite

Granitic rocks have been described from the western part of the Talkeetna mountains 3/, but such types are present only sparingly in the Willow Creek mining

3/ Capps, S. R., and Tuck, Ralph, 1935, The Willow Creek-Kashwitna district: U. S. Geol. Survey Bull. 864-B, pp. 95-115.

district. Granite has been observed only in the western part of the mining district where it is clearly intrusive into older quartz diorite. One small pluglike body is exposed on the high point of the ridge 3½ miles northeast of the Lucky Shot mine. It was not traced westward. Elsewhere along the western part of the area mapped, granite occurs in dikes as much as 10 feet wide in the quartz diorite. The granite is a light-colored, mafic-poor, medium-to fine-grained rock composed of essential plagioclase ranging from 7 to 16 percent anorthite, quartz, and potash feldspar, generally microcline. Muscovite and biotite are present in small amounts but hornblende is lacking. In places small quantities of myremekite and microcline microperthite have developed.

Dike rocks

General Statement:--In Capps's original discussion of dike rocks in the Willow Creek district, it was stated that dikes are

> ...not abundant...most are only a few feet wide and occur in places where their longitudinal extent can be traced for only short distances. Their areal extent is small, and...were large enough to justify their representation on a map of the scale of Plate III...4/ (scale is 1/62,500).

4/ Capps, S. R., op. cit. p. 48.

The possible significance of the dikes was overlooked, and only brief descriptions were given by Capps. J. C. Ray 5/, on the other hand, recognized that dike rocks

5/ Ray, J. C., op. cit. p. 181.

might be of value in locating faulted vein segments, but he made no effort to bear out this idea, and no dikes were shown on his geologic map. The productive veins lie almost entirely within the monotonous quartz diorite, and by detailed mapping of dikes it may be possible to obtain quantitative data regarding late major fault displacements of the gold quartz veins. Detailed surface mapping by the writer has shown that dikes are indeed not too abundant, but several have been observed (see fig. 2).

Dike rocks in the quartz diorite may be subdivided into four general groups: 1) lamprophyre, 2) diabase, 3) aplite, and 4) pegmatite. For the most part only the lamprophyre dikes fall into a recognizable pattern, and these have been mapped in considerable detail. All dikes are older than the post-ore faults with the possible exception of the diabase which follows the major transverse fault pattern and may be contemporaneous with the post-ore faulting. No dikes have been traced with certainty across major fault zones, but more detailed mapping in areas where dike segments are now known may prove fruitful. Age relations of the various dike types have been determined from scattered observations throughout the district, and the sequence from oldest to youngest has been found to be aplite-pegmatite, lamprophyre, and diabase. Observations along the outcrop of the Lucky Shot vein show that the lamprophyre dikes are older than the vein and have been offset by post-mineral movement in the plane of the vein. Whether the movement within the vein was normal or reverse could not be determined with certainty. At the Mabel mine an aplite dike has been offset about 10 feet by reverse movement in the plane of the vein. A similar type of movement is also believed to have taken place in the plane of the Independence vein, but it is unlikely that movement within the veins would affect the use of dike displacements in marking offsets due to late transverse major faults, for even if dike displacements by vein fissures were large, it would be a unique circumstance which would prevent dike segments on opposite sides of late major faults from being effective keys to measurement of the major fault offset.

Lamprophyre:--The lamprophyre dikes are dense, fine-grained, greenish-black rocks which break with great difficulty. Aside from their color they generally can be recognized in hand specimens by the presence of hornblende phenocrysts which attain 0.2 inch in length in some specimens. The weathered surface of these dikes has a dark gray color not unlike that of the host quartz diorite. Gray-colored lichens grow on most weathered surfaces of the dike rocks and quartz diorite and as a result it is often extremely difficult to distinguish the two unless fresh specimens are obtained. This undoubtedly explains why more occurrences of the dike rocks have not been reported although lamprophyre dike float is conspicuous where present. The dikes range in width from a few inches to about 6 feet. Contacts with the quartz diorite are always sharp. The strike ranges from about 090° to 180°, but the most prevalent trend is 120° to 140°. The dip is moderate and always to the southwest. Almost always these dikes follow strong southwest-dipping joints: in places they may be observed to break across from one joint to another. Faulted segments of the lamprophyre dikes are continuous in places for as mush as 2000 feet, and segments belonging to the same dike have been traced for nearly a mile (see fig. 2). Offsets by minor faults are numerous, and in places these dikes are severed by the major transverse faults of the mining district. It is in this regard especially that they may be of considerable geologic--and hence, economic--importance.

Diabase:--Diabase dike segments have been observed in only a few localities within the mining district. These dense black rocks resemble the lamprophyre superficially, but they do not conform to the lamprophyre dike pattern and should therefore be differentiated. The diabase is always badly sheared and in this respect contrasts sharply with the lamprophyre which is solid and compact. Noteworthy also is the almost complete lack of phenocrysts in the diabase, whereas hornblende phenocrysts characterize the lamprophyre. As a result, distinctions in the field can be made easily, and microscopic determinations are not needed.

The few diabase dike segments mapped range in width from 2 feet to about 20 feet. No segments could be traced for more than a few hundred feet. The general strike of these dikes is between 095° and 110°; the dip is steep in a northerly direction. In contrast the lamprophyre dikes trend slightly more northerly and always dip in an opposite direction, that is, to the southwest.

The smaller number of diabase dikes within the Willow Creek district suggests that these might be of considerably more value than other dikes as marker horizons for major fault offsets, but the general conformity of the diabase dikes in strike and dip with one or more major post-ore faults of the area lessens their correlation value, although they may be useful in determining displacements along northeastward-trending faults. In all probability the shattering in the diabase is due to later shearing along major faults which they occupy.

Aplite-Pegmatite:--The aplite-pegmatite dikes are not uncommon, but because of the usual weathered, lichen-covered surfaces they are easily overlooked. Along the southern margin of the batholith much aplite-pegmatite dike float has been observed, and it is here that these dikes are most abundant. They do not conform as a rule to any general pattern, although locally they may follow the strong southwest-dipping joint set. Widths range from about 1 inch to 5 feet. These dikes typically split, pinch, and swell along the strike, and only rarely can they be traced for more than a hundred feet or so. Strikes and dips vary radically in many places. Locally these dikes have been useful in marking very minor fault displacements, but it is doubtful if they would ever be of value in correlating movement along major faults of the district. Aplite may occur independent of pegmatite but often the aplite and pegmatite are found together in the same dike and have been treated together here. Where aplite and pegmatite do occur in the same dike the aplite may form the finer grained border with pegmatite in the central band, but aplite flanked by pegmatite borders have also been observed.

Recent work was shown the pegmatites to be slightly radioactive due to small amounts of uraninite, thorite, allanite, and cyrtolite 6/.

6/ Moxham, R. M., and Nelson, A. E., 1951, Radioactive pegmatite minerals in the Willow Creek mining district, Alaska: Trace Elements Investigations Report 74-C.

Schist

Where schist borders the quartz diorite in the Willow Creek mining district it is a strongly foliated, silvery-gray rock, with foliation trending northeastward and generally dipping moderately to the northwest. The foliation is a flow cleavage formed by the subparallel alinement of muscovite plates. Plagioclase feldspar porphyroblasts up to 0.2 inch across are generally strongly developed, and occasionally needles of black tourmaline up to 0.4 inch long are seen. Throughout most of the area the schist is highly fissile due to the extreme development of muscovite, but in some places the rock is more massive due to a greater amount of feldspar and lesser development of mica. Small open folds superposed on the regional northward-dipping foliation are numerous adjacent to the batholith contact, but 1½ miles to the south isoclinal folds predominate. Original bedding is generally obscured by the metamorphism, but in many stream beds and in underground workings at the Thorpe mine color banding representing compositional layering is clearly seen. Where original bedding has been recognized, it is parallel to the foliation of the schist. Dikes are not common in the schist, and particularly are dike types similar to those in the quartz diorite lacking.

Sedimentary rocks

Sedimentary rocks comprised largely of conglomerate, arkose, shale, and sandstone, dip gently to the south away from the quartz diorite batholith. Coal beds and lava flows are locally interbedded, and in places the sequence is gently folded 7/. Where the sedimentary sequence is in contact with the batholith the beds

7/ Capps, S. R., 1915, The Willow Creek District, Alaska: U. S. Geol. Survey Bull. 607, pp. 32-33.

are steeply tilted. Southwest of the mapped area the sedimentary rocks are separated from the quartz diorite by the older mica schist. Study of the sedimentary rocks is outside the scope of the immediate mapping project of the mining district, and these rocks have only been observed in the southeastern part of the district. Here the basal conglomerate bed, about 100 feet thick, contains well-rounded boulders of quartz diorite as much as 5 feet in diameter together with a variety of cobbles and pebbles in an arkosic matrix. Other rock types in the conglomerate include quartzite, mafic dike material (?) or greenstone (?), aplite, and chert. The arkose is generally fine grained and breaks with great difficulty. It has a striking resemblance to the quartz diorite from which it was undoubtedly derived in part. Shales and sandstones which crop out to the south were not observed by the writer.

Structural Features

General structural features and age relations

The southern border of the Talkeetna quartz diorite batholith as exposed in the Willow Creek mining district is flanked by mica schist and by sedimentary rocks composed chiefly of conglomerate, arkose, sandstone, and shale. Nowhere is the contact between the quartz diorite and mica schist exposed, but comparison of the strikes and dips of foliation in the mica schist with those in the nearby quartz diorite suggests that the structures of these two rock types are locally unconformable. The grade of metamorphism does not increase as the quartz diorite contact is approached. Indeed, in some places away from the contact deformation is stronger in the schist, and the possibility of a fault contact between these two rock types should be considered. Jointing, which is so characteristic of the quartz diorite, is only poorly developed in the schist.

In the southeastern part of the mining district the basal conglomerate of the younger sedimentary sequence is in contact with the gabbro phase of the Talkeetna batholith. Here the bedding is steeply tilted to the south at an angle of 58° to 70°. The degree of dip decreases rapidly away from the contact. Quartz diorite boulders in the conglomerate attest to the younger age of the sedimentary sequence, and these boulders together with arkosic beds mineralogically similar to the quartz diorite indicate at least partial derivation of the sedimentary rocks from the igneous rock types. The steep dip of the sedimentary sequence at the batholith front is in all probability due to a renewed uplift of the intrusive mass.

Structural features as related to the quartz diorite

Foliation:--Megascopic foliation due to primary mineral orientation is generally moderately developed in the quartz diorite. It has a rather constant trend to the northeast and moderate dip to the northwest. It is most easily seen in areas where hornblende is the predominant mafic mineral.

Inclusions and segregations:--Inclusions in the quartz diorite are exceedingly common. These are comprised of at least three different rock types. They are composed of similar minerals but differ in texture, grain-size, and relative proportions of the various minerals. By far the greatest number of inclusions are fine- to medium-grained, gray or gray-black, elongate bodies generally lying in the foliation planes of the quartz diorite. They are characteristically porphyritic and show hornblende and feldspar phenocrysts 0.25 to 0.5 inch long, but some are entirely even grained. As a result of weathering they often stand out in relief above the host quartz diorite. Most are 1 to 2 feet long and are but a few inches wide.

A second type of inclusion is a fine-grained, light-colored quartz diorite. It is most often found as large blocky masses several feet across. Contacts may or may not be conformable with the foliation of the host rock. A foliation within the included material is common, but this is generally not conformable with the contact nor with the foliation in the host rock. Within these large inclusions of fine-grained quartz dioritic material smaller elongate mafic inclusions of the type described above may occur rarely.

A third type of included material in the quartz diorite is confined largely to an area near the south end of the divide separating Craigie and Upper Willow Creeks, although scattered outcrops at high elevations from other parts of the district are known. The rock is typically dark green to black, very fine grained, and often strongly banded. The largest block of this material seen was about 100 feet long and had a maximum width of 3½ to 4 feet. It is a tabular body lying essentially horizontal and parellel with the foliation in the surrounding host rock. Alternating light and dark bands ranging in width from a knife edge to several inches characterize this inclusion. Fine-grained mafic-rich bands separated by light-colored somewhat aplitic bands predominate.

Segregations, or schlieren, of mafic minerals are much less common than inclusions in the quartz diorite. They are not restricted areally, although most have been observed in areas where hornblende is the predominant mafic mineral. The schlieren are typically black due to the concentration of biotite and particularly hornblende. They are often coarser grained than the surrounding quartz diorite but are mineralogically similar differing only in the relative abundance of various minerals. Fine-grained schlieren of light colored minerals, predominantly quartz and feldspar, are present to much lesser extent.

Joints:--Three sets of joints characterize the quartz diorite except for a zone about a mile wide parallel and immediately adjacent to its southern border where only a few joints in no definite pattern occur. In any one area only two of the three joint sets may be conspicuous, but throughtout the quartz diorite the southwest-dipping set of joints is always prominent. The average trend of this set is 135° and dip is about 40° to 45° southwest. These joints are often developed over many tens of feet and are characterized in general by remarkably smooth flat faces. They may be further characterized by barren quartz filling 1 to 4 inches wide, and in many places they are the site of chalcopyrite-molybdenite veins, aplite and lamprophyre dikes. The second joint set trends just west of north and dips steeply to the east. A third joint set strikes nearly due east-west and may dip steeply either to the north or south. This third joint set is poorly developed and is marked by irregular surfaces.

Although the southwest-dipping joints may very locally appear to have exerted control on the emplacement of certain of the productive gold quartz veins, these joints are not the locus of the productive veins as described by Capps 8/. Where

8/ Capps, S. R., op. cit., p. 56.

quartz veins are parallel to the southwest-dipping joints prospecting may be expected to be unprofitable.

Faults:--A variety of faults ranging from a few inches to a few hundred feet displacement cut the quartz diorite. The major faults of large displacement divide the quartz diorite into a number of segments in which productive gold quartz veins are confined. These faults establish a well-defined fracture pattern and are most important in a study of the ore deposits because they are post-ore in age. In several places they truncate valuable ore shoots. The major post-ore faults appear to define a conjugate set trending to the northwest and dipping to the southwest and northeast. They are believed to be mostly of normal displacement. The faults are wide zones of comminuted, generally strongly altered quartz diorite which exceed 100 feet from hanging-wall to footwall in some mines. Horses of little-altered quartz diorite are present in places within the major fault zones. The Gold Cord fault on the 200 level of the Gold Cord mine is 120 feet wide, and the Martin fault which cuts off the Independence vein on the south is reported to be 140 feet wide on the 900-level southwest crosscut. Diplacements on these major post-ore faults are all believed to be large, but in only a few places is the magnitude of the offset known. Faulted segments of the rich Gold Bullion vein have never been located. Older maps of the Fern mine show that the horizontal component of displacement of the Fern vein where it is cut off on the west end, is approximately 300 feet. To the east it is displaced a similar distance by a second post ore fault. If the vein north of the Gold Cord fault is a continuation of the segment south of the fault, the horizontal component of displacement is of the order of 125 feet. Displacement of the vein at the Mabel mine along the Mable fault has also been about 125 feet, and according to J. C. Ray the horizontal component of displacement on the fault in the east end of the Lucky Shot mine is more than 600 feet 9/. Although the total offset on the major post-ore faults has been

9/ Ray, J. C., op. cit., p. 211.

considerable, at any one point within the fault zone the movement may have been small. Where the Martin fault is exposed in a small stream tributary to Craigie Creek from the southeast, for example, foliation within the thoroughly altered quartz diorite of the fault zone is well preserved over a width of several feet. In the Martin mine a segment of the minable quartz vein was reported to lie in part within the Martin fault. Thus there is some evidence that the greatest amount of movement along post-ore faults may have been confined to a narrow part of the fault zone.

Because marker horizons in the quartz diorite are generally lacking, detailed mapping of lamprophyre dikes was carried out in an attempt to determine the quantitative displacement of various faults. No dikes have been traced with certaintly across the wide northwestward-trending post-ore faults, but many narrow northeastward-trending faults, with displacements as great as 200 feet, have been mapped and a general pattern of displacement on them established (see fig. 2). With few exceptions the displacement of dike segments north of the northeastward-trending faults has been relatively to the east and probably downward. The same pattern probably holds for the major northwestward-trending faults, so far as can be told from underground studies.

Other minor faults have displaced productive veins a few feet but generally not seriously enough to hinder mining operations. In the Gold Cord mine, however, so-called "strike faults" created a serious problem in mining. These faults trend nearly due north, the same as the gold quartz vein, but dip to the east, a direction opposite to that of the vein. The mine record shows that these faults are hinge faults of normal displacement. Displacement increases to the north. In contrast to the wide northwestward-trending post-ore fault zones, strike faults in the Gold Cord mine are at most only a few inches wide. Two strong strike faults are also known in the Independence mine, but these do not offset the vein seriously.

There has also been post-mineral movement in the planes of productive veins. Shearing has caused late fracturing, and in the Fern and Snowbird mines the quartz in places has been reduced to lenses and pods of sugary, granular texture. The relation of aplite dikes to the vein at the Mabel mine indicates that movement in the plane of the vein was reverse. Stoll 10/ reports shearing has caused a slight

10/ Stoll, W. C., 1944, Relations of structure to mineral deposition at the Independence mine, Alaska: U. S. Geol. Survey Bull. 933-C, pp. 201-216.

reverse displacement along the Indepencence vein.

Veins

General statement

Excluding pegmatites, which in places contain minor amounts of chalcopyrite and bornite, the veins may be divided structurally into two groups, a younger group occupying early major shear zones in the tectonic pattern of the quartz diorite, and an older group generally conforming to the strike and dip of southwest-dipping joints. The quartz bodies in the early shear zones comprise the productive veins of the district. They in turn form two groups, one trending 060° to 080°, dipping 30° to 60° to the north, and one trending nearly due north, dipping from a few degrees to about 45° to the west. Veins along the southwest-dipping joint planes are, in contrast, nonproductive. They can in turn be subdivided into three types on the basis of mineral content. The more common type is composed of chalcopyrite, molybdenite, pyrite, and quartz; the second type is made up of pyrite, stibnite, and quartz; the third contains coarsely crystalline quartz with sparse pyrite, sphalerite, possibly other sulfides, and coarse gold.

Veins trending with southwest-dipping joints

By far the most abundant veins in the district are vuggy, glassy quartz veins containing molybdenite, chalcopyrite, and pyrite. They stand out readily due to the blue and green colors of azurite and malachite which have resulted from surface alteration of chalcopyrite. Limonite also is conspicuous in some vein outcrops. Most of these veins are only a few inches in width, and with few exceptions they pinch out in short distances along the strike. A few veins as much as 1 foot wide have been observed. The strike ranges from 130° to 150°, always in conformity with the local variations in the strike of the joints; the dip is generally between 35° and 50° southwest. The quartz is often somewhat sheeted, and these fractures generally are coated with a veneer of molybdenite. Oxidation of the molybdenite in some veins has yielded a yellow or orange-yellow coating, possibly ferrimolybdite(?) or powellite(?).

A second vein type conforming to the structural pattern of the southwest-dipping joints of the quartz diorite contains pyrite, stibnite, and glassy quartz. Whether it is a distinct vein type deposited under different temperature conditions or at a different time than the chalcopyrite-molybdenite veins is not certain, but it may be pointed out that no specimens have been found showing molybdenite and stibnite associated in the same vein. The pyrite-stibnite veins are of the same magnitude as the chalcopyrite-molybdenite veins but are far less common.

In a few places vuggy quartz veins filling the southwest-dipping joints contain coarse flakes of free gold. Pyrite, sphalerite, and possibly other sulfides are associated sparsely. A vein of this type in the first valley northeast of the Gold Cord mine has been unprofitably exploited. The gold has been deposited as coarse plates around quartz crystals. Two other joint quartz veins containing sparsely distributed gold crop out on the ridge top east of the Gold Cord mine upper working.

Productive gold quartz veins

Distribution and Attitude:--Productive gold quartz veins are confined almost entirely to an area in the quartz diorite along the southern border of the Talkeetna batholith. This area is about 8 miles long in a nearly easterly direction and about 4 miles wide. In general, the productive veins fall into two groups: 1) one trending 060° to 080° and dipping 30° to 60° to the north, 2) the second trending approximately north and dipping from a few degrees to about 45° to the west. These trends are average trends only; it is common for both the strike and dip of any one vein to vary, in places considerably, along the strike and down dip.

Character:--Introduced vein material consists essentially of quartz but with some carbonate and small amounts of pyrite, arsenopyrite, sphalerite, chalcopyrite, tetrahedrite, nagyagite, altaite, galena, stibnite(?), gold, and rarely scheelite. In only a few places have the shear zones been entirely filled and replaced with introduced vein matter. Commonly much mechanically ground up and altered country rock is present, and throughout the shear zones ground up diorite now reduced to clay gouge may form an essential part of the "vein". Clay gouge also occurs generally as a selvedge along the vein walls permitting free breaking.

The northeastward-trending ore bodies are in strong shear zones which are as much as 25 feet wide in some places. The quartz may have a sugary texture and most often occurs in long lenses, aggregates of small lenses, or branching quartz stringers a few inches wide. Slickensided blocks of partly altered country rock together with sticky clay gouge in places make up much of the zone.

The north-trending ore bodies, on the other hand, often form well-defined veins which in places occupy the entire width of the shear zone. Widths of 6 feet are not uncommon, and a few zones much wider than this have been reported. Often a strong band of quartz is confined to one wall or the other of the shear zone, but in many places the vein is composite in nature. Hanging-wall quartz and footwall quartz may be separated by altered and comminuted quartz diorite, or there may be, in addition, a central band of quartz with cross stringers connecting with the footwall or hanging-wall. In many places hanging-wall quartz seems to be more prominent. Generally, minable quartz is 1 to 3 feet wide, although vein segments containing wider zones of minable quartz have been exploited, and in places veins composed of two or more distinct bands of quartz only 6 to 8 inches wide have been mined. Quartz may pinch out along the strike as well as dip and pass into barren parts of the shear zone composed only of broken up and altered quartz diorite fragments. One or two exceptional areas have been reported where shear zone material was actually productive.

Quartz varies from gray through blue gray to milky white, and may or may not be banded. Coarsely crystalline quartz with open vugs characterize certain veins, but these have almost never been worked successfully. Quartz in productive veins contains few or no vugs but is badly sheared.

Banding in the quartz stands out clearly in many thin sections. Bands of very fine grained quartz alternate with bands of slightly coarser grain. The coarser bands in places show elongate, clear quartz crystals with well-developed termination on one end; these are believed to represent open space filling. Late carbonate filling around terminated quartz crystals has been observed in many specimens suggesting that open spaces may have existed for some time.

Quartz microbreccia is common throughout the veins, and microbrecciation has been suggested as a mechanism which opened early quartz to the gold bearing solutions. This is perhaps borne out by the occurrences of quartz microbreccia in rich portions of some veins, but microbrecciated quartz is also common in veins which are of low tenor or are barren of gold. In one specimen what appeared to be a microbreccia zone contained small quartz crystals with well developed hexagonal outlines. This may represent a group of crystals torn off from an open cavity wall and later cemented together.

Mineralogy and Paragenesis of the Ore:--The ore of this district is essentially a free-milling gold quartz ore with small amounts of sulfides, estimated to be about 2 or 3 percent by weight. Small quantities of tellurides are present locally. J. C. Ray reported the gold to be about 950 fine 11/. So far as can be determined

11/ Ray, J. C., op. cit., p. 191.

from polished specimens, binocular study of hand specimens, and heavy mineral separations, the variety of ore mineral is small. Because of the scarcity of sulfides and tellurides, and because of their small grain-size when present, it was not possible to determine completely the paragenetic relationships in the ore.

Quartz was probably the first mineral introduced into the shear zones. Original quartz of the quartz diorite was supplemented by this introduced quartz which filled open spaces and replaced some constituents of the host rock. Much of the quartz deposited by the circulating solutions probably came from the breakdown of silicates in the shear zone and also to some extent from the altered wall rock. Polished specimens show even more strikingly than thin sections that open space filling is characteristic of the ore. It is common to find elongate, terminated quartz crystals which formed in open cavities, later filled predominantly by carbonate, but also by late quartz and sulfides.

Pyrite is the most common sulfide, occurring as striated cubes, pyritohedrons, and irregular grains. Within the veins it is restricted for the most part to the earlier quartz. Most pyrite grains are typically fractured, and the larger grains often are filled with late carbonate, rarely quartz. Nagyagite, chalcopyrite, and gold have also been observed as fracture fillings in pyrite.

Only in a few specimens was sphalerite observed. It occurs as small isolated masses in quartz, but more often it is associated with other sulfides. It generally contains randomly oriented blebs of chalcopyrite and further is completely, or nearly completely, surrounded by a narrow fringe of chalcopyrite. In specimens showing a sphalerite core surrounded by chalcopyrite, the chalcopyrite is generally in turn enclosed by tetrahedrite which is closely associated with nagyagite and altaite.

Chalcopyrite fills fractures in, surrounds, and replaces grains of pyrite and was probably the next sulfide to be deposited after sphalerite. In a few places irregular flakes of gold occur in the chalcopyrite, but this relation alone does not establish the relative ages of the two minerals.

Tetrahedrite occurs sparingly, but closely associated with nagyagite and altaite with which it is probably nearly contemporaneous. Where sphalerite occurs, a surrounding fringe of chalcopyrite, in turn enclosed by tetrahedrite is usually present. Small blebs of tetrahedrite may form directly in the sphalerite and chalcopyrite, but in general it seems to have followed the depostition of chalcopyrite. In places it forms mutual lobes with nagyagite. Spectrographic analyses of ore samples made in the chemical laboratory of the U. S. Geological Survey showed traces of mercury. The mercury is likely contained in the tetrahedrite. Older reports of cinnabar in the gold veins thus have support. Cinnabar is occasionally found in similar gold quartz veins in other mining districts.

Perhaps the most important discovery resulting from a study of the Willow Creek ores is the identification of undoubted tellurides. Tellurides have been reported in the past but never identified. An earlier report of tellurides at the Lucky Shot mine 12/ was checked by J. C. Ray who reported no tellurium in the sample analysed 13/. The present study has shown that in some ore at the Fern mine and at

12/ Smith, P. S. 1932, Mineral industry of Alaska in 1929: U. S. Geol. Survey Bull. 824, p. 18.
13/ Ray, J. C., op. cit. pp. 191-192.

the Schroff-O'Neil mine nagyagite, a sulphotelluride of lead and gold, is an important mineral especially in the richer ore, and free gold always shows a strong preference for it, even where fractured pyrite, an ideal host, is present in the same specimen. The gold commonly occurs as irregular blebs or flakes in the nagyagite, and the paragenetic relationship is difficult to determine. Binocular examination of some ore samples shows plates of gold largely surrounding nagyagite suggesting a younger age for the gold. But from polished section study the possibility of contemporaneous deposition at least in part cannot be overlooked. In some specimens nagyagite occurs associated with euhedral quartz suggesting some open space filling around earlier quartz. In other places nagyagite fills fractures in earlier pyrite. Some nagyagite forms along the borders of chalcopyrite and may protrude into chalcopyrite along an otherwise straight contact. Wherever nagyagite was observed it was found to contain small irregular grains of the lead telluride, altaite, scattered through it. The nagyagite, altaite, and gold appear to be very closely related in age and were undoubtedly among the latest metallic minerals to be deposited.

Galena has been identified in only a few specimens where it occurs in masses which exhibit good cubic cleavage. Judging from polished section studies, it is not an important sulfide in the ore. Gold is usually closely associated with the galena cubes either as flakes adjacent to or within the galena. Altaite is also present as small blebs in galena. Galena was deposited later than sphalerite, but its position in the paragenetic sequence is not known with certaintly.

Arsenopyrite is a conspicuous sulfide as large individual grains or in cruciform twins, but nowhere was gold seen in direct association with it, although J. S. Ray has reported gold replacing arsenopyrite 14/.

14/ Ray, J. C., op. cit., pp. 190, 192.

Stibnite may occur sparingly in the ore. A cluster of long radiating needles of a strongly anisotropic metallic mineral, believed to be stibnite, was present in one sample examined. Its paragenetic position is unknown.

Scheelite is present sparingly in most of the productive veins, but like stibnite, its position in the paragenetic sequence is unknown.

Gold in the Willow Creek district ores is extremely fine grained. A few flakes as much as 0.03 inch across were seen, but most measured only a few thousandths of an inch across. Gold occurs as isolated flakes or blebs strung out within the quartz, and sometimes as fillings around early euhedral quartz crystals, but commonly directly associated with the sulfides and tellurides. Pyrite is the only metallic mineral which can be shown to be definitely older, in part, than the gold for gold in places fills fractures in pyrite grains. Aside from this relationship in polished sections gold is seen as irregular blebs in pyrite, chalcopyrite, and nagyagite; or as stringers in juxtaposition of one of these minerals; or these minerals may rarely be enclosed by gold. These relations tell nothing definite of the relative ages. However, the close association of gold with the late mineral nagyagite and the apparent restriction of gold to nagyagite in some places where nagyagite is present as minute stringers in other sulfides, suggests that the gold is younger than most metallic minerals except nagyagite with which it may be contemporaneous in part.

There is little doubt that movement in the planes of the veins was at least recurrent if not continuous during the period of ore deposition. The fact that most sulfides are fractured, but that certain ones are definitely younger or older than others is ample evidence for this conclusion. Quartz deposition apparently continued for a long period of time for in places it is also found to cut and replace especially pyrite and earlier quartz.

Late carbonate, particularly as small veinlets, is conspicuous. Many of the smaller carbonate veinlets exhibit matching walls and are attributed to open space filling, but some of the larger veinlets have ragged contacts with the quartz suggesting that replacement to a certain degree took place. Even where distinct veinlets cannot be recognized, the hexagonal outlines of quartz crystals surrounded by carbonate--as well as sulfides, tellurides, and gold--are a good indication of open space filling.

Wall rock alteration:--Hydrothermal alteration of the wall rock has been intense adjacent to the productive quartz veins, but it seldom extends more than 10 to 12 inches beyond the quartz filling. Hydrothermal activity has resulted notably in the destruction of hornblende, biotite, plagioclase, magnetite, and even chlorite, whereas sericite, carbonate, sulfides and quartz(?) were formed as a result of this activity. This type of wall rock alteration typically accompanies what Lindgren has termed "sericitic and calcitic gold-silver veins" 15/. These geins were later classed by Lingren as mesothermal 16/.

15/ Lindgren, W., 1900, Metasomatic processes in fissure-veins: Trans. A.I.M.E., vol. 30, pp. 664-668.
16/ Lindgren, W., 1933, Mineral Deposits, 4th. Ed., pp. 544-555.

Adjacent to the vein quartz, the quartz diorite wall rock has been bleached to a chalky or chalky gray-green color due particularly to the alteration of mafic constituents to chlorite and sericite, and due to the sericitization of the plagioclase feldspar. With decrease in intensity of alteration the wall rock becomes darker green and finally passes into the gray color of fresh quartz diorite.

Carbonates have developed more or less throughout the whole altered zone, whereas sericite is most strongly developed nearest the vein filling and chlorite farthest from the vein filling. Pyrite and arsenopyrite, also new products of hydrothermal alteration, are found nearest the vein filling. Secondary quartz is present in a few places.

Many of the original minerals in the wall rock are partially or completely destroyed. Plagioclase is almost always completely altered to patches of carbonate and fine-grained sericite, but in places several inches from the vein the feldspar twinning is sometimes preserved. Some distance from the vein remnants of hornblende in places are associated with chlorite-biotite alteration products, or hornblende crystal outlines may enclose dull brown biotite. Biotite in most parts of the altered zone have broken down to chlorite, and nearest the veins the chlorite is in turn altered to muscovite and carbonates. Magnetite, a common constituent of fresh quartz diorite, is present only sparingly in the altered wall rock, but leucoxene is abundant locally suggesting that original magnetite may have been slightly titaniferous. In most places quartz in the altered wall rock is badly strained and often shattered, and where alteration has been intense the quartz has been replaced by sericite.

Within some parts of the veins small horses of quartz diorite have been partially preserved. This altered quartz diorite within the vein--known as vein fill-in some places comprises most of the shear zone. Generally, the plagioclase is altered to carbonate and sericite just as in the altered wall rock. Quartz grains and any feldspar grains which survive are typically highly fractured and filled with small stringers of fine-grained sericite and carbonate. In a few places very fine-grained, recrystallized quartz may fill these fractures. Apatite is always preserved, but the mafic minerals biotite and hornblende generally do not survive, although in some specimens biotite plates with wavy extinction have been seen. As in the altered wall rock, patches of carbonate and muscovite laths probably mark the position of original mafic minerals. In general, alteration of the mafic minerals within the shear zones has gone completely through the chlorite stage and only muscovite and carbonate now remain. Opaque minerals are usually absent or occur only sparingly. Especially iron must have been removed from the partially altered quartz diorite in the shear zones, and this may now be represented by the iron sulfides in the wall rock or in the vein quartz.

Mineralogical changes in wall rock adjacent to productive parts of a vein are markedly similar to alteration adjacent to barren portions of the same vein. Consequently there appear to be no diagnostic mineralogical criteria of wall rock changes which may be useful as a guide to ore.

Ore Shoots:--Most of the mines in the Willow Creek district have been developed only to shallow depths, and the ore shoots are not well delineated on stope sheets. In some mines ore shoots have been truncated by major transverse faults, and it is not possible to determine the pattern of the shoot. Stope sheets of the Independence mine do indicate a general moderate rake of elongate ore bodies to the north, and this is in agreement with information obtained from a former mine foreman. But in some places the ore bodies are entirely irregular in shape. In no mine is quartz always ore, but rather the minable bodies are distributed within larger areas of lower tenor or barren quartz. It must be remembered, of course that mining has exceeded the limits of the richer shoots, and no stope map will give a representative picture of these shoots unless careful assays have been made

Structural Control of Ore Bodies:--Certain irregularly shaped ore bodies may be due to late fracturing of vein quartz where no other structural elements are concerned, but some of the richer ore shoots have formed at intersections of the main veins with smaller "intersecting" veins, erroneously called "feeder" veins locally. In the Independence mine several intersecting veins have been exposed. These veins are generally narrow--a few inches mostly, but as much as 24 inches in the extreme most trend northwestward and dip to the southwest. One such vein is reported to have intersected the Independence vein on the now inaccessible 700 level. Here a considerable amount of ore was mined. It will be noted that the intersection of the "feeder" vein and the main vein on the inaccessible 700 level would plunge to the northwest--the direction of rake of the ore shoot as described by a former mine foreman. More recently a rich ore shoot was mined on the 1400 level. The occurrence was somewhat unique for not only did a strong north-trending vein intersect the main Independence vein, but the main vein reversed dip and formed a small plunging synclinal structure at the intersection. At the Fern mine the ore mined during 1949-50 was actually in the intersecting vein but very close to the main Fern vein. The small intersecting veins would appear to be either splits off the main veins, intersecting veins of the other productive shear zone, or veins trending with the southwest-dipping joints. In those areas where intersections have been loci of ore shoots, the tenor of ore decreases in the smaller intersecting vein. Consequently it is believed that the main veins acted at the principal channelways for the gold-bearing hydrothermal solutions. In some places not related to other structural elements ore was deposited in somewhat irregular bodies where quartz was fractured or open spaces existed as a result of late stress probably applied in a direction similar to that which formed the shear zones; in other places adjustment to late stress took place at vein intersections which were even more favorable for fracturing of the brittle quartz.

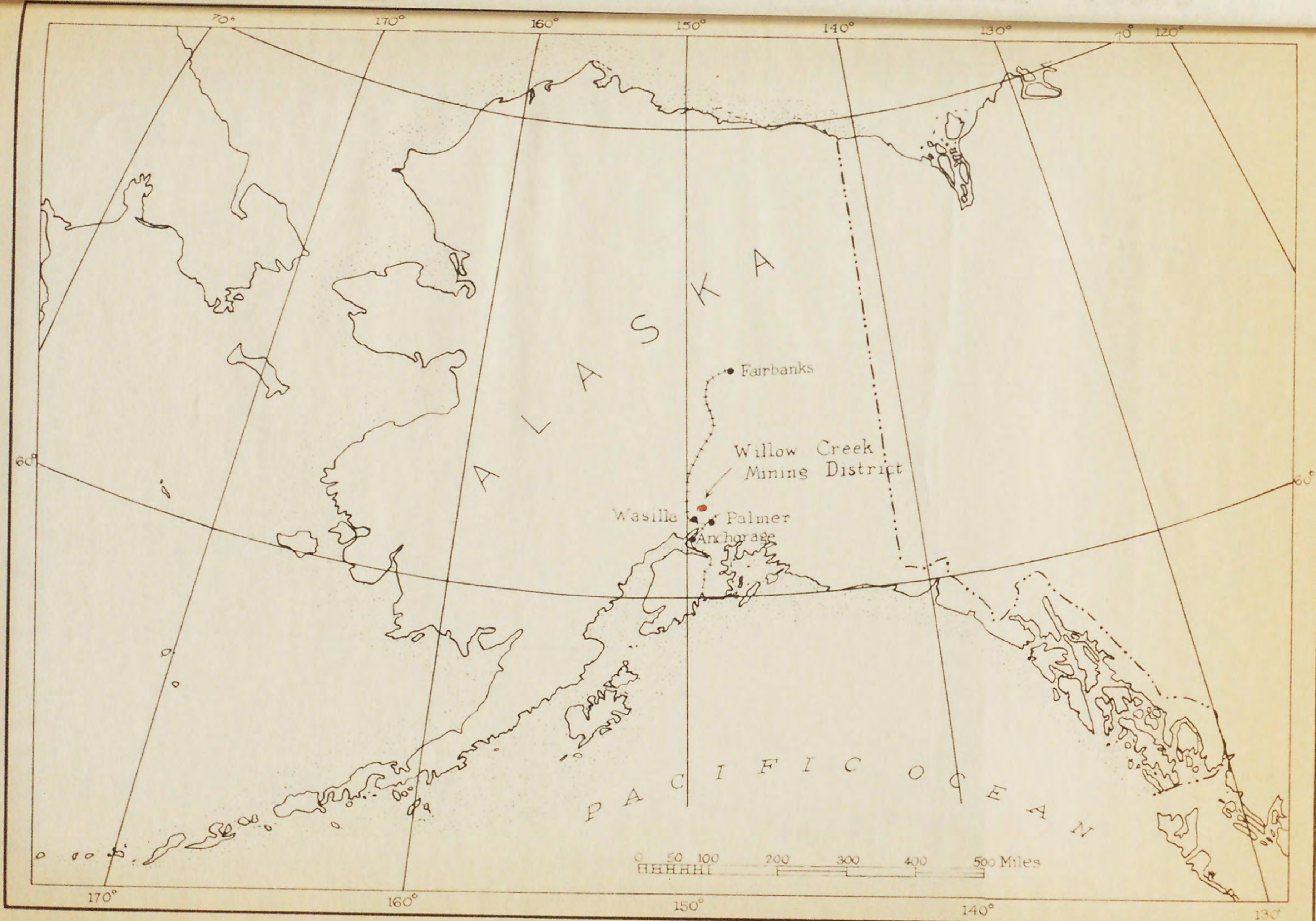
Mining in the Willow Creek district has not been carried far enough to more than suggest that certain features are particularly important. This holds true for the rake of ore shoots. It will be noted, however, that the intersections of the main productive shear zones, and most of the intersections of veins of the southwest-dipping joint set with either of the productive shear zones, will rake to the northwest. Thus if this feature is significant, one would expect ore shoots of the north-trending veins to rake to the right as an observer looks down the dip of a vein, and to the left in the case of northeastward-trending veins. An obvious exception is the occurrence of an ore shoot where two veins, parallel in strike but differing in dip, intersect.

Placers

Prior to the discovery of lode gold in 1906 some placer gold was recovered from the western part of the mining district, but placer mining has never attracted much interest. Original concentrations of gold in stream gravels have been destroyed by glaciation and reconcentrations have been slight. The restricted development of post-glacial stream gravels and the occurrence of innumerable boulders dropped by the glaciers have been discouraging to the placer miner.

In 1950 two placer properties were prospected, one near the mouth of Grubstake Gluch and one near the mouth of the next stream to the west. Both streams head in the mica schist and drain into Willow Creek. The gold in these placers appears to have come from quartz lenses in the schist. Poorly sorted gravels on a high bench just east of the mouth of Grubstake Gulch yield some free gold on panning. A slight depression at the top of this bench may represent a former stream channel of Grubstake Gulch, and it is possible that locally reworked gravels exist which could be mined successfully on a small scale.

Duplicating Service, Department of the Interior, Washington 25, D. C. 3303



This map is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

FIG. 2

GEOLOGIC MAP OF THE WILLOW CREEK MINING DISTRICT, ALASKA