Geology and Ore Deposits of the Willow Creek Mining District, Alaska

GEOLOGICAL SURVEY BULLETIN 1004

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By RICHARD G. RAY

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A study of the general and economic geology of a lode gold mining district in southern Alaska, with particular emphasis on the significance of vein, dike, and fault patterns

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By Richard G. Ray

ABSTRACT

The Willow Creek district is a small but important lode-gold mining district along the southern border of the Talkeetna Mountains in southern Alaska. Gold production to date (1950) has been somewhat less than $18,000,000, or about 5 percent of Alaska's lode-gold output.

Productive gold quartz veins occupy shear zones in the southern margin of the Talkeetna batholith, which lies south of the Alaska Range proper, a prominent physiographic feature of central Alaska. The igneous mass in the Willow Creek area is made up largely of quartz diorite that is flanked on the southwest by an older schist of unknown age and on the southeast by sedimentary rocks of Tertiary(?) age. Dikes of lamprophyre, diabase, aplite, and pegmatite are especially common in the quartz diorite. The intrusion of igneous rocks probably took place in late Mesozoic time.

The shear zones containing productive gold quartz veins are cut by post-ore faults believed to be of normal displacement. Post-ore faults are known to offset the veins as much as 600 feet horizontally.

Formation of the veins was in large part by cavity filling and to lesser extent by replacement. 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 they do not persist for great distances along the shear zones. Quartz bands characteristically swell and pinch, and pass into zones barren of quartz. The shear zones themselves, however, are notably persistent but are everywhere limited along the strike by major post-ore faults.

The ore is essentially a free-milling gold quartz ore containing minor amounts of pyrite, arsenopyrite, sphalerite, chalcopyrite, tetrahedrite, galena, scheelite, possibly stibnite, as well as the tellurides, nagyagite, altaite, and coloradoite(?). The gold is very fine grained and is generally difficult to see with the naked eye even in ore that assays as much as $300 to the ton. It may occur as small isolated flakes or as blebs strung out in quartz; in places it forms as fillings around earlier euhedral quartz crystals; but most commonly it is directly associated with the sulfides and tellurides. The gold is particularly closely associated with the telluride, nagyagite. Where nagyagite is abundant the tenor of the ore is generally high.

Wall-rock alteration within a few inches of the veins was intense. Sericitization and carbonatization predominated, but there was some pyritization and in the outer parts of the alteration zone chloritization was important. The hydrothermal solutions which caused this alteration probably were responsible also for the quartz and the later gold-sulfide-telluride deposition. Gold was deposited where favorable conditions existed, particularly at vein intersections where the quartz host was perhaps more susceptible to fracturing.

All mines in the Willow Creek district are small, and no mine has produced more than $1,000,000 in gold in any one year. Most of the profitably minable veins have been exploited only to shallow depths, the most extensive

operations being carried about 1,500 feet down the dip. Yet the veins in the Willow Creek district are mineralogically and structurally very similar to the veins in other mining districts where mining has been carried to a depth of several thousand feet. If the geologic similarity of the Willow Creek veins to veins in some other productive mining districts has any significance, then the Willow Creek district has hardly been scratched and its future should be promising.

INTRODUCTION

Since 1907 the Willow Creek district, except for a few years, has contributed to Alaska's lode-gold production. Activity in the mining district was at its peak between 1931 and 1942. The depression period of the early 1930's was undoubtedly favorable to the gold mining industry, and the increase in the price of gold in 1934 from $20.67 to $35 an ounce was an added stimulus to the expansion of mining activity.

The importance of the Willow Creek mining district, both as a currently producing district and as a potentially expanded mining camp, had long been apparent, and a program of additional detailed surface and underground mapping was considered desirable. Because of the priority of other work and the cessation of gold mining during World War II, further investigation of the Willow Creek district was postponed until 1948 at which time the writer began a detailed mapping project of the mining district as part of the U. S. Geological Survey's program of minerals investigations in Alaska. Such a study of the Willow Creek mining district would not only afford a long-needed investigation of one of Alaska's important mining areas but would serve as a background for carrying out the broader regional study of the Talkeetna batholith of which the mining district is an integral part.

PREVIOUS WORK

During a reconnaissance survey of the Talkeetna Mountains in 1906 Paige and Knopf (1907) examined the Willow Creek area briefly. The rock types were mapped in a general way and their microscopic features were described. A geologic map of the Talkeetna Mountains on a scale of 1:250,000, which included the Willow Creek district, was published, but no detailed geologic data were recorded. Lode gold had not yet been discovered, and only one small placer mine was being operated successfully. Considerable interest in gold lodes was soon to develop, however, and several properties were active when Katz made a brief tour of the mining district in 1910. He described these mining properties and discussed the vein characteristics as known from the relatively small number of surface and underground workings at that time (Katz, 1911).

The first comprehensive study of the Willow Creek district was made by Capps in 1913. A preliminary report of his work was published the following year (1914), and in 1915 a final report (Capps, 1915) was completed. Capps mapped the area on a scale of 1: 62,500, described the mining properties then in operation, and gave the first detailed account of the veins and their characteristics. Although some of Capps' conclusions are now found to be incorrect and others questionable, his work was an important contribution to the general geology of the mining district. Some of these conclusions can hardly be criticized justifiably when the short periods of study and the limited development of the district at that time are considered.

Brief accounts of mining activity subsequent to Capps' study were published in various progress reports on Alaskan minerals investigations, but no further work of importance was done in the district until 1931 when J. C. Ray examined and described the gold quartz veins in some detail (Ray, J. C., 1933). He was the first to recognize that more than one vein type exists, and his work on the veins stands as an important contribution to the geologic knowledge of the mining district. Ray's mapping was confined largely to underground workings, however, and added little to the knowledge of surface geologic features.

Aside from the collection of material for a short bulletin on one of the mines (Stoll, 1944) no other significant work was done in the Willow Creek district prior to 1948.

PRESENT WORK

This report embodies the results of three summer seasons of mapping in the mining district—from 1948 through 1950. Approximately 10 months were devoted to field work. Besides surface studies, investigations were made underground at the Lonesome mine on the Little Susitna River; the Fern mine on Archangel Creek; the Webfoot prospect on Archangel Creek; the Snowbird mine on Reed Creek; the Mabel mine, near the top of the divide west of the junction of Reed and Archangel Creeks; the Independence, Gold Cord, and High Grade mines on Fishhook Creek; the Kelly-Willow prospect on upper Willow Creek; and the Thorpe mine on Grubstake Gulch. The War Baby and Lucky Shot mines on Craigie Creek, important producing mines in the recent past, were almost completely inaccessible and could not be studied. The Gold Bullion mine, abandoned long ago, was also inaccessible, as was the Martin mine on Fishhook Creek.

Recent mining activity has been focused in the area of the Little Susitna River drainage, but the name "Willow Creek district" has been retained from older usage even though the mines in the Willow Creek drainage for the most part have been worked out or closed down for many years.

SCOPE OF INVESTIGATION AND METHODS OF FIELD STUDY

Previous investigations in the Willow Creek mining district have been incomplete mainly because of the short periods of time that competent geologists have been assigned to the area, and because of the relatively small amount of development work that had been carried out when those geologists were in the area. Published data are consequently incomplete. Previously published geologic maps fail to show any of the post-ore faults, which are of considerable economic significance to the mining district. Structural detail is almost entirely lacking on the older maps. Vein, dike, and fault patterns have been entirely neglected or treated only superficially. The possible economic significance of a thorough study of these features led to the present detailed investigation of the Willow Creek district.

In the present study, vein, dike, and fault patterns have been given considerable attention, and an attempt has been made to relate the vein pattern to structures within the igneous rocks. The post-ore faults of the district have been investigated by detailed ground traverses and by air reconnaissance, plus the limited trimetrogon and vertical photography available. Complete vertical photographic coverage may aid greatly in outlining the pattern of major faults more thoroughly.

Over a large part of the area geologic mapping was carried out on a scale of 1: 6,250, on photostat enlargements of the U. S. Army Engineers Idaho Peak quadrangle. Topography, alone or in conjunction with Brunton compass bearings on three or more prominent landmarks, was used extensively as a guide to locating positions for plotting field observations. Altitudes were determined by aneroid barometer checked twice daily against a known datum. In a few areas where large scale mapping was desirable transit surveys were made. Final compilation of all surface data is on a scale of 1: 20,000.

Much attention has been given to dikes in the igneous rocks as possible means for measuring fault displacements that cannot otherwise be determined in the monotonous quartz diorite of the district.

All the productive quartz veins with one exception are within the area of dioritic country rock, and the present investigation was confined largely to a study of the quartz diorite and the associated gold lodes. Only brief field examinations were made of the mica schist and sedimentary rocks which border the quartz diorite. The quartz diorite and related dike rocks on the other hand were studied in considerable detail and are thoroughly discussed herein particularly because of their significance in relation to the gold quartz veins but also because additional mapping now planned in conjunction with the broader study of the Talkeetna batholith is expected to encompass similar rock types and structures.

ACKNOWLEDGMENTS

Without the generous cooperation of mine operators and others in the Willow Creek mining district much of the work described in this report could not have been undertaken, and it is with pleasure that their help is acknowledged. The writer wishes particularly to express his appreciation to Mr. A. L. Renshaw, formerly at the Gold Cord mine, who made camp facilities available during 1948 and 1949. Others with whom he has had the pleasure of associating include Mr. J. B. Renshaw at the Gold Cord mine, Mr. Lloyd Hill and Mr. Charles Cope at the Lonesome mine, Mr. A. G. Dodson at the Fern mine, Mr. Phil Holdsworth at the Snowbird mine, Mr. Clyde Thorpe at the Thorpe mine, and Mr. Ralph Tracy at the Kelly-Willow prospect. The cooperation of Messrs. Stoll, Lane, Swedes, Brooks, O'Neil, and Schroff is also acknowledged.

During the summer of 1948 the writer was assisted in the field by Ollie Smith, Jr. In 1949, C. K. DeWitt, Jr., was employed as field assistant. Bernard W. Wilson, geologist, was assigned to the party in 1950 and assisted in both field and laboratory duties. John C. Reed, Jr., was employed as field assistant.

GEOGRAPHY

LOCATION AND ACCESSIBILITY

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 23 miles by dirt road from the town of Wasilla, on the main line of the Alaska Railroad, and 21 miles from Palmer, on a spur of the Alaska Railroad. Both highway and rail connections link Palmer with Anchorage, 50 miles to the south.

Roads within the mining district are maintained by the Alaska Road Commission only during the summer season. Snow usually melts by early June, and roads remain open until sometime in October. During the winter most parts of the district are inaccessible except when roads are made passable at the expense of the mines.

TOPOGRAPHY, CLIMATE, AND VEGETATION

The Willow Creek district is within an area that was intensely glaciated. Much of the district now presents features of typical "biscuit board" topography. Steep-walled cirques and hanging valleys separated by sharp arêtes are characteristic. At the head of Archangel Creek and the Little Susitna River small glaciers are still present, but the glaciers have long since receded from most of the valleys. The glaciation was of the alpine type as attested by the jagged, sawtooth ridges which give most of the district a rugged and impressive ap-

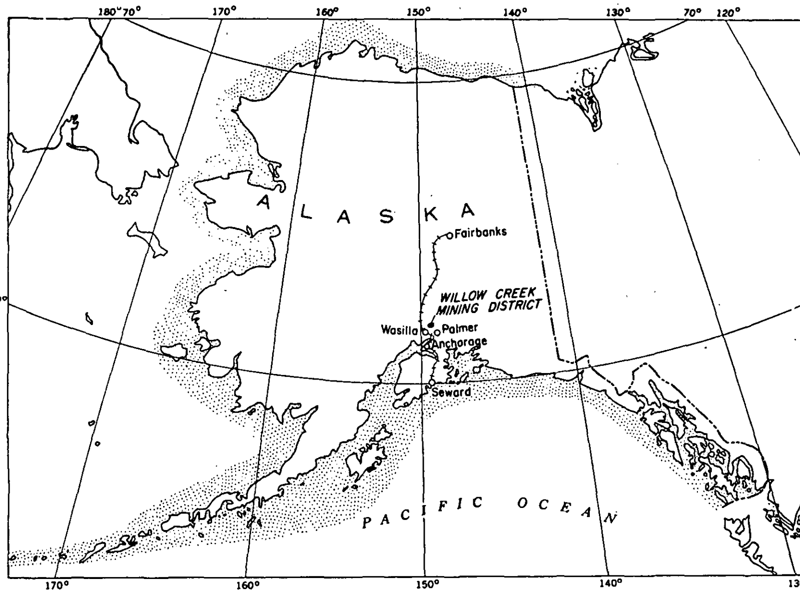

FIGURE 1.—Index map of Alaska, showing location of Willow Creek mining district.

pearance (fig. 2). Some of the peaks attain altitudes of as much as 6,000 feet. Relief totaling as much as 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 containing blocks of quartz diorite commonly 10 to 15 feet across. Valley floors were originally covered with glacial debris but have almost everywhere been modified somewhat by post-glacial drainage. Above the mouth of Archangel Creek, however, the Little Susitna River valley has retained its U-shaped cross section. Along their lower courses Willow Creek and the Little Susitna River particularly, comprising the major drainage of the Willow Creek district, flow in deep notches cut in the glacial debris, and as a result benches of this glacial material now remain some distance above the stream courses. Post-glacial stream gravels have not developed to any extent, 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.

No official weather records are available for the mining district, but weather stations are maintained at Wasilla and at Palmer. Records for the Wasilla station since weather records were initiated in 1945, and for the Palmer station for the period 1941 through 1950 are shown on tables 1, 2, 3, and 4 (U. S. Weather Bureau reports, 1941–50).

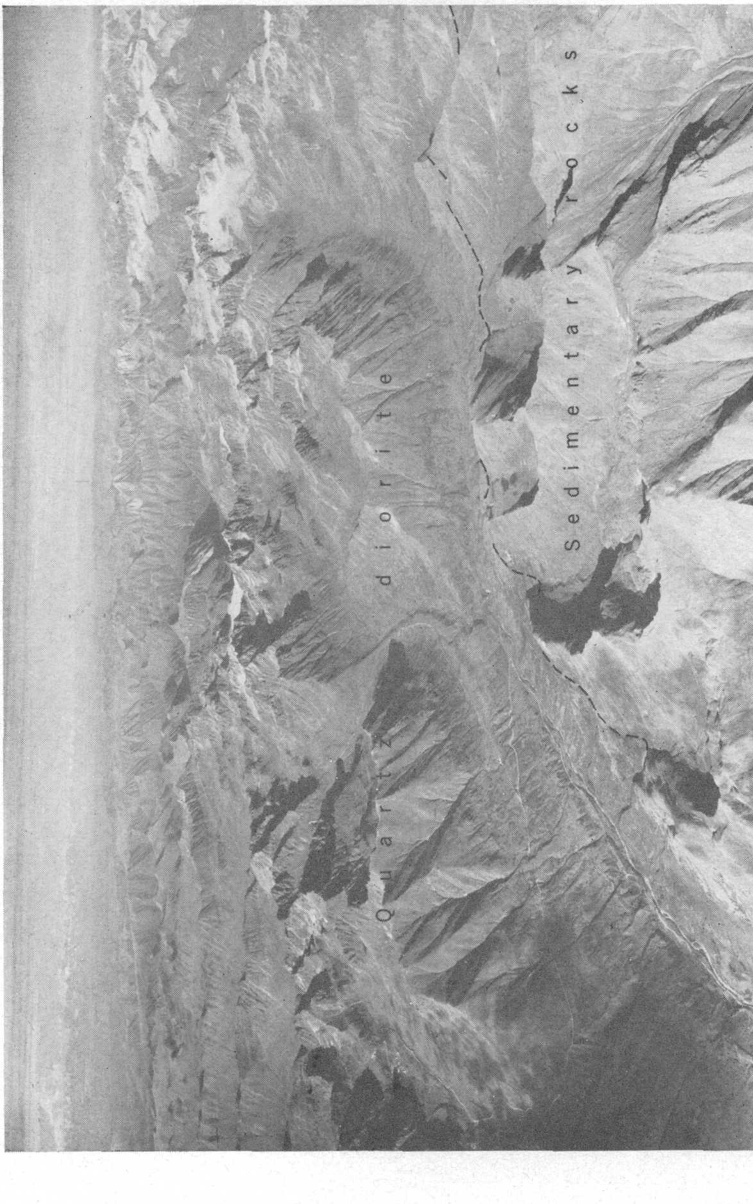

FIGURE 2.—Aerial view of part of the Willow Creek mining district looking north. Little Susitna River in left foreground. (East-west distance through center of photograph is approximately 7 miles.)

TABLE 1.—*Records of temperature and precipitation at Wasilla, Alaska, 1945–50* [1]

Year	Temperature (degrees Fahrenheit)					Precipitation (inches)	
	Average for year	Highest		Lowest		Total for year [2]	Total snowfall [3]
		Amount	Date	Amount	Date		
1945	34.3	76	July 9	−30	Feb. 13	19.06	No record
1946	32.5	82	July 27	−35	Mar. 16	15.57	67.0
1947	35.8	86	July 18	−50	Jan. 26	15.43	No record
1948	32.0	85	June 17	−32	Dec. 30	18.42	Inc. record
1949	(4)	80	Aug. 28	−43	Jan. 7	22.88	(4)
1950	(4)	82	July 9	−34	Jan. 11	11.91	(4)

[1] No record prior to 1945.
[2] Includes snowfall.
[3] Divide by 10 to convert to approximate equivalent in water.
[4] Record not available.

TABLE 2.—*Monthly mean high and low temperatures at Wasilla, Alaska, 1945–50* [1]

	Temperature (degrees Fahrenheit)	
	High	Low
January	21.8	−0.7
February	26.6	4.7
March	34.3	14.6
April	45.0	22.4
May	57.7	32.7
June	65.7	38.9
July	68.2	44.4
August	65.9	41.8
September	56.7	36.0
October	43.8	26.1
November	28.8	9.8
December	20.8	.9

[1] No record prior to 1945.

In general it is somewhat cooler and wetter in the mining district during the summer months and warmer during the winter months than at either Wasilla or Palmer. Personal observations in the district from the end of May through September have shown daytime temperatures between 40° and 50° F. to be common, above 65° uncommon. Marked deviations from the normal seasonal temperatures and precipitation can be expected, however. The summer of 1948 was very cool and wet, whereas the summer of 1950 was unusually warm and dry. The normal winter snowfall is reported to be between 4 and 5 feet, but during the winter of 1948–49 between 16 and 20 feet of snow fell. Local residents report this to be the severest winter in 42 years. Although most of the snow falls during the winter months light snow-

TABLE 3.—*Records of temperature and precipitation at Palmer (Experimental Farm), Alaska, 1941–50*

Year	Temperature (degrees Fahrenheit)					Precipitation (inches)	
	Average for year	Highest		Lowest		Total for year [1]	Total snowfall [2]
		Amount	Date	Amount	Date		
1941	37.4	75	June 3	−21	Jan. 1	11.07	32.0
1942	37.4	80	June 23	−22	Dec. 22	15.98	29.5
1943	38.2	83	June 21	−23	Jan. 3	18.14	42.0
1944	37.4	79	July 6	−32	Jan. 29	21.13	40.4
1945	34.8	75	July 9	−23	Feb. 13	18.58	54.5
1946	32.8	78	July 1	−29	Dec. 15	12.60	47.0
1947	35.0	83	May 29	−41	Feb. 4	12.60	37.5
1948	33.5	81	June 17	−22	Dec. 7	14.32	54.4
1949	(3)	77	July 5	−30	Dec. 24	19.05	(3)
1950	(3)	78	June 28	−22	Jan. 10	9.77	(3)

[1] Includes snowfall.
[2] Divide by 10 to convert to approximate equivalent in water.
[3] Record not available.

TABLE 4.—*Monthly mean high and low temperatures at Palmer (Experimental Farm), Alaska, 1941–50*

	Temperature (degrees Fahrenheit)	
	High	Low
January	22.1	4.6
February	29.3	11.3
March	35.2	17.3
April	45.7	26.0
May	57.9	35.9
June	65.9	43.6
July	66.6	56.8
August	65.4	44.8
September	56.7	38.6
October	43.7	27.9
November	27.8	12.0
December	20.9	4.2

falls may 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.

GENERAL GEOLOGY

The Willow Creek mining district is underlain largely by intrusive rocks that form the southern margin of the great Talkeetna batholith of south-central Alaska. The intrusive rocks—predominantly quartz diorite, and lesser gabbro and granite—are the most significant rocks in the area since productive gold quartz veins are almost entirely confined to them. Metamorphic and sedimentary rocks flank the intrusive mass on the south. The areal distribution of rock types is shown on plate 1.

The metamorphic rocks are composed mostly of mica schist, locally strongly folded. Nowhere in the Willow Creek district is the contact between the schist and quartz diorite exposed, but the schist is believed to be the oldest rock in the area and to have been intruded by the quartz diorite. No apophyses of quartz diorite have been noted in the schist, however. Quartz veins, almost entirely barren of metallic minerals, are common in the schist sequence, but local gold placers in the southwestern part of the mining district are believed to have their source in the schist.

Flow structures and inclusions in the quartz diorite suggest that the igneous rocks now exposed cannot be far from the original roof of the intrusive mass. This peripheral area of the larger intrusive mass was particularly susceptible to fracture, and structural channelways developed in which gold quartz veins and associated lamprophyre, diabase, aplite, and pegmatite dikes were deposited. Productive gold quartz veins conform to a pattern distinct from that of the joints which commonly are loci of nonproductive quartz veins. All veins and dikes were disrupted by major faulting that took place late in the tectonic history of the intrusive mass.

In the southeastern part of the district younger conglomerate, arkose, sandstone, and shale were deposited. Where the sedimentary rocks are in contact with the quartz diorite they are tilted to the south at a steep angle; away from the contact the sedimentary rocks are gently folded.

METAMORPHIC ROCKS

SCHIST

The schist which borders the Willow Creek mining district on the southwest is a strongly foliated, silvery-gray rock, with foliation trending northeastward and dipping predominantly to the northwest at a moderate angle. The foliation is a flow cleavage formed by the subparallel alinement of muscovite plates. Plagioclase porphyroblasts as much as 0.2 inch across are generally strongly developed, and occasionally needles of black tourmaline as much as 0.4 inch long are seen. Throughout most of the area the schist is highly fissile because of the extreme development of muscovite, but in some places the rock is more massive owing to a greater amount of feldspar and lesser development of mica. Quartz is everywhere a common constituent of the schist. 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 as a result of metamorphism, but in many stream beds and in underground workings at the Thorpe mine color banding, interpreted as compositional layering of the original sediments, is clearly seen. Where original bedding has been recognized, it is parallel to the foliation of the schist.

Three types of lineations are commonly encountered throughout the schist. The first type is comprised of fold axes that plunge gently to the northeast or southwest. A second lineation, generally parallel to the fold axes, is formed by crinkled muscovite plates which manifest themselves as minute ridges on the foliation surfaces. Axial planes of these crenulations form an incipient fracture cleavage—or slip cleavage—which is at a large angle to the flow cleavage. In some places a true fracture cleavage unrelated to these minor crenulations has developed, and locally it is more conspicuous than flow cleavage. The more conspicuous fracture-cleavage planes dip northeastward, but no consistent pattern of the fracture cleavage was observed. A lineation of slickensides on fracture-cleavage planes nearly always has a gentle plunge to the east. Quartz lenses are displaced as much as 1 inch along some fracture-cleavage surfaces.

Joints are not well developed in the schist and no consistent joint pattern could be mapped. Locally cross joints perpendicular to fold axes are developed on a small scale. Numerous barren quartz lenses, from 1 to several inches thick, pinch and swell along the foliation of the schist. Less commonly thin stringers of quartz are parallel to the cross joints.

Lenses of mafic rocks are reported to be present locally throughout the schist. Float of a green mafic rock is common in Grubstake Gulch, but only one lens of such material was found in place. This crops out below the forks of the stream. The lens of mafic rock at this locality is about 6 to 8 feet wide and has the structure of the enclosing schist, which strikes[1] about 080° and dips steeply to the northwest. The mafic material has been altered and is now represented by massive serpentine, talc schist, and actinolite schist.

Dikes are not common in the schist, and particularly scarce are dike types similar to those in the quartz diorite. Irregular small lenses of pegmatite entirely dissimilar in appearance to that in the quartz diorite are found infrequently. Segments of a silicic dike crop out on the road just west of Hatcher Pass, in Hatcher Creek, on the

[1] All compass readings in this publication are referred to the azimuth system.

spur south of Hatcher Creek, and particularly in the basin 1 mile south of the lake just west of Hatcher Pass. This rock is light reddish gray to tan colored, and in hand specimens has a strong resemblance to fine-grained quartzite. With the exception of pyrite, which is present as an accessory constituent, individual minerals can be definitely identified only by microscopic examination. Although hand specimens appear to show an even grain, the rock is porphyritic and contains small phenocrysts in a very fine grained groundmass. The phenocrysts are largely zoned plagioclase with an average composition near An_{30}, but a few masses of chlorite showing boundaries suggestive of original hornblende phenocrysts are also present. Simple twins of plagioclase phenocrysts are conspicuous. In a few grains multiple twins are seen. Mafic constituents are lacking for the most part. The groundmass is comprised mainly of fine lathlike grains of plagioclase although there is also a small amount of quartz. The dikes range from a few inches to about 30 inches in thickness and in most areas are parallel to the foliation of the schist, but crosscutting dikes were observed in a number of places. Shearing within the dikes indicates that they were mechanically altered by the deformation that affected the surrounding schist.

Microscopically the schist is characterized by albite porphyroblasts in a groundmass predominantly of muscovite and quartz. The porphyroblasts, nearly pure albite in composition, are generally untwinned or show a large simple twin. As a rule the apparent long dimension of the plagioclase crystals is parallel to the foliation, but crystals with long dimensions at angles ranging from small to 90° to the foliation are present. No linear orientation of plagioclase crystals has been observed, however. The albite porphyroblasts contain numerous inclusions of quartz, muscovite, and especially a black opaque material strung out in discontinuous beaded masses. The black material may be carbonaceous. The black carbonaceous(?) stringers are occasionally S-shaped and suggest rotation of the albite porphyroblasts which developed during metamorphism of the schist. Tourmaline needles are locally developed parallel to the foliation planes; within the foliation planes their orientation is random. The long laths of muscovite which give the rock its foliation—or flow cleavage—are commonly strongly contorted into minute folds and crenulations. These crenulations are locally so tight that they give rise to an incipient fracture cleavage at a large angle to the flow cleavage. Chlorite is intimately associated with much of the muscovite. Quartz is also a common constituent, forming as long narrow stringers composed of fine-grained aggregates parallel to bands of muscovite. Where minute crenulations are present, the quartz laminae, like the muscovite, bend around into intricate folds. Quartz is often seen as embayments in the albite porphyroblasts and as stringers within or extending into porphyroblasts, usually parallel to the stringers of carbonaceous(?) material. Quartz stringers parallel to bands of carbonaceous(?) material appear to be relict structures which rotated with the porphyroblasts during growth. Irregular projections of quartz into the porphyroblasts likewise probably represent material being engulfed by growing porphyroblasts although the existing relations do not preclude the possibility of replacement of the feldspar by quartz. Locally, clinozoisite is abundant in the schist. Ragged granular aggregates of garnet are also present as are a few plates of biotite. Apatite is present in irregular masses in the quartz laminae.

Although the schist is strongly contorted in certain areas, the grade of metamorphism, as indicated by the mineral assemblage quartz-albite-muscovite, is low.

IGNEOUS 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. Gneissoid structure is especially well developed in the finer grained phase of the quartz diorite along the margin of the intrusive mass.

The quartz diorite is generally medium grained. Visual inspection shows that the average grain size probably ranges from about 0.05 to 0.2 inch. A finer grained phase is generally restricted to the southern border of the igneous mass. Plagioclase, quartz, biotite, and hornblende are the chief minerals. Microcline, orthoclase, sphene, apatite, zircon, and magnetite comprise the accessory constituents. The rock texture is hypautomorphic-granular; plagioclase, hornblende, and, in places, biotite are present as euhedral to subhedral grains between which later anhedral quartz crystallized. Megascopically the medium-grained quartz diorite can be roughly subdivided into two types. In the first, large crystals of hornblende are conspicuous, and biotite occurs chiefly as small plates. The second type contains scattered large books of biotite and generally small crystals of hornblende. No sharp boundaries between these two medium-grained rock types exist, and no uniform distribution of them could be mapped, although, in a general way, the more noticeably biotitic phase occupies an area nearer the southern border of the intrusive mass; hornblende is more prominent megascopically towards the center of the intrusive mass. Despite the division of the medium-grained quartz diorite into two types, based on apparent megascopic predominance of hornblende or biotite, micrometric analyses have shown biotite to be present in excess of hornblende (table 5).

The quartz and plagioclase content of the quartz diorite is roughly uniform throughout the district. The feldspar tends to become more calcic and more strongly 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 types of quartz diorite to the north except that hornblende appears to be present in slight excess over biotite (table 5). So far as can be determined from field observations the finer grained phase and the normal medium-grained quartz diorite are parts of the same intrusive sequence. The finer grain-size reflects the cooler environment in which those rocks crystallized. The strong foliation is probably a result of the proximity of the finer grained phase of the igneous mass to the original wall rock.

TABLE 5.—*Micrometric analyses of quartz diorite showing approximate volume percentages of mineral constituents*

Specimen locality	Plagioclase (percent anorthite)	Biotite	Hornblende	Quartz
One half mile south of Kelly-Willow prospect	67 (39%)	10	3	20
1½ miles southeast of Gold Cord mine	64 (34–38%)	9	8	18
Mabel mine	61 (36–38%)	8	5	24
1½ miles northwest of Fern mine	68 (38–48%)	8	7	17
1 mile north of Snowbird mine	59 (32–48%)	16	8	15
First spur north of road southeast side of Craigie Creek valley [1]	64 (35–44%)	9	10	17
Spur south of Lake 1 mile east of Lucky Shot mine [1]	57	9	13	20
Top ridge northwest side Craigie Creek valley 3.2 miles northeast of Lucky Shot mine	65 (37–42%)	15	4	17

[1] Indicates finer grained border phase.

MINERALS OF THE QUARTZ DIORITE

Plagioclase feldspar.—Plagioclase feldspar is by far the most abundant mineral of the quartz diorite, constituting 57 to 68 percent of the rock by volume. Its composition ranges from approximately An_{32} to An_{48}.

The plagioclase occurs as subhedral to euhedral crystals all of which are twinned. Rarely are any of the twin lamellae bent or deformed in any way. A combination of simple and multiple twins parallel to the side pinacoid was observed in the plagioclase of all thin sections. Multiple twins parallel or nearly parallel to the basal pinacoid are also commonly present. In quartz diorite within 1 mile of the southern border of the igneous mass the plagioclase most commonly exhibits a combination of complex twins parallel to the side pinacoid—the albite-Ala B and the albite-Carlsbad—but these twin types are not restricted areally in distribution. Twins parallel or nearly parallel to the basal pinacoid are conspicuous, but no basal cleavage was observed associated with them. Designation of such twins as acline rather than pericline twins, therefore, is hardly justifiable inasmuch as the "rhombic section" (the composition plane of pericline twinning) is nearly parallel to the basal pinacoid (the composition plane of acline twinning) in plagioclase of the compositions here considered.

Feldspar zoning is not as conspicuous in quartz diorite adjacent to the border of the igneous mass as it is in rocks nearer the center of the intrusive mass. Four miles within the batholith, feldspar zoning is extreme. Zoning does not progress continuously from more calcic in the core to more sodic at the border, but is rather an oscillatory type zoning alternating from calcic to sodic, back to calcic, etc. The extremes in composition do show a general lowering of anorthite content toward the rims, but the rhythmic zoning complicates this feature. The striking zoning superposed on twin types gives unusual patterns which can be explained only on the basis of the variety of complex twins present.

Quartz.—The second essential component of the quartz diorite is quartz which crystallized as interstitial masses between other minerals. In a few places it seems to have eaten into surrounding feldspar grains. The quartz characteristically shows an undulatory extinction whether it is near the southern border of the igneous mass or well within the batholith. Quartz makes up 15 to 24 percent of the quartz diorite by volume.

In many specimens the quartz exhibits an irregular fracture pattern. Many of the grains contain small hairlike inclusions which are randomly oriented. Close inspection under high magnification reveals that these hairlike inclusions are commonly offset by slippage along small fractures in the quartz. The inclusions are so fine as to require changing at times the focus of the microscope to detect them. These are truly microlites; their small size precludes positive identification. They are restricted to the quartz and consequently serve to distinguish this mineral when they are present. Associated in many quartz grains are rows of minute gaseous or liquid inclusions.

Biotite.—The most abundant mafic mineral in the quartz diorite is biotite, which makes up 8 to 16 percent of the rock by volume. In some areas it is conspicuous because of its large size. Books measuring 0.2 inch across are common and plates as much as 0.3 inch across have been noted. In general the biotite is in smaller crystals, however, and consequently appears to be less abundant than hornblende, although micrometric analyses show it to predominate slightly over the latter in most specimens (see table 5). The β index of the biotite is nearly constant throughout the district ranging from about 1.648 to 1.652.

The biotite alters readily, principally to chlorite. In a few specimens the chlorite has a brown interference color, but far more common is chlorite showing a deep blue interference color. Alteration took place most easily along cleavage planes of the biotite, and it is common to find chlorite feathered into a biotite grain along the cleavage. Small islands of biotite surrounded by chlorite are also common locally. They probably represent a late stage in the alteration of biotite to chlorite. Occasionally epidote and prehnite formed along cleavage planes of the biotite. Inclusions of zircon and apatite are abundant. Slightly bent biotite plates attest to minor stresses which have affected the quartz diorite, probably during an advance stage of cooling of the igneous body.

Hornblende.—Hornblende is also a typical constituent of the quartz diorite, ranging in amounts from 3 to 13 percent by volume. Hornblende crystals range in size from microscopic to 0.4 inch in length. Twins parallel to the front pinacoid are common.

Within the Willow Creek district the hornblende is probably quite constant in chemical composition, so far as can be determined from optical properties. The β index, determined in the hornblende of several specimens from scattered localities, both adjacent to the margin of the igneous mass and at distances of as much as 4 miles within the mass, is rather constant, near 1.676. The extinction angle, $Z \wedge c$, is 16° to 17°. Results of optic angle determinations were inconsistent. A very strong dispersion was noted, and it seems likely that this was a factor in giving inconsistent optic angle measurements. An abundance of sphene and in some places ilmenite as accessory constituents in the quartz diorite suggests that the hornblende may contain titanium, and to this in part may be attributed the extreme dispersion. In all specimens the optic sign is negative. Pleochroism is: X=colorless or pale straw yellow; Y=olive green; and Z=blue green; absorption is $Z>Y>X$.

The hornblende is distinctly primary. There are no pyroxene relicts or crystal outlines which would suggest secondary hornblende. Hornblende probably crystallized throughout a wide temperature range. In places it occurs poikilitically included in plagioclase; in others, plagioclase is included within the larger hornblende. Small crystals of apatite and magnetite within the amphibole are common, and in some amphibole crystals epidote appears along cleavage planes. The epidote is undoubtedly secondary. Hornblende is noticeably resistant to alteration and has been changed in part to chlorite only in specimens where all biotite has been converted to chlorite.

Accessory minerals.—Microcline and orthoclase are important accessory minerals in some specimens, but in general they occur in amounts less than 1 percent. They appear to have crytallized out late as interstitial masses similar to quartz.

Magnetite is the most common accessory mineral. It is present mostly as irregular grains closely associated in position with the mafic minerals biotite and hornblende. In places it occurs as inclusions in the biotite and hornblende. Apatite grains are often present in turn as inclusions in the magnetite. In some thin sections cloudy borders of leucoxene or fine-grained aggregates of sphene occur around the black opaques and suggest that this mineral is ilmenite or titaniferous magnetite. The general abundance of sphene is in harmony with this idea.

Sphene is prominent as an accessory mineral, often closely associated in position with the mafic minerals, but scattered grains in plagioclase are not uncommon. Many large crystals with typical diamond-shaped cross section and symmetrical extinction have been observed.

Apatite typically formed as inclusions in hornblende, biotite, and magnetite, although it is by no means restricted to them. Least abundant of the accessory minerals is zircon. Like apatite, it occurs as small inclusions in hornblende and biotite, but it is not restricted to these minerals.

Secondary minerals present in small amounts include sericite, chlorite, calcite, epidote, prehnite, and leucoxene. The epidote and prehnite commonly formed along the cleavage planes of biotite where they may be associated with chloritization. Epidote has also been observed in hornblende and in plagioclase. In the feldspar it may take the form of small rounded grains or small irregular veinlets cutting completely across the feldspar crystal.

Chlorite is prominent as an alteration product of biotite, and in some surface rocks the only vestige of biotite is seen in aggregates of chlorite shreds. It is unusual to find chlorite that has formed from hornblende, although this occurrence has been noted in a few rocks, especially in intensely altered fault zones.

Sericite is confined almost entirely to the feldspars, which often take on a spangled appearance as a result. This mineral formed typically as small shreds scattered throughout the feldspar crystals. In those rocks containing a small amount of microcline the alteration to sericite is more noticeable in the plagioclase feldspar than in the potash type. Calcite and epidote are associated with the sericitization of feldspars in some specimens; calcite is also common as minute lenses along the cleavage of biotite. Leucoxene formed as borders around ilmenite or as small isolated masses in close proximity to ilmenite.

ORBICULAR PHASE OF THE QUARTZ DIORITE

About 1 mile northeast of the Snowbird mine camp rare orbicules of diorite occur in loose quartz diorite boulders. These blocks are localized in an area about 20 feet square adjacent to a small pluglike intrusive mass of andesine pegmatite. The orbicules are believed to have formed at the contact of the pegmatite and quartz diorite. At a second locality east of Reed Creek and 1 mile south of the Snowbird mine camp crude orbicules are present in a second pluglike mass of pegmatite. The pegmatite is characterized by euhedral andesine crystals as much as 1 inch across associated with interstitial microcline, orthoclase, and quartz.

The orbicules are triaxial ellipsoids with short and long axes measuring as much as 6 and 10 inches respectively. Minerals similar to those in the quartz diorite matrix occur in conspicuous concentric bands in the orbicules (figs. 3 and 4). Plagioclase feldspar is the main constitutent, and biotite the second most prominent mineral. Hornblende occurs sparingly, and quartz is present only as secondary fillings of fractures and open spaces. All accessory minerals of the quartz diorite matrix are present in the orbicules. Radial growth is characteristic of the plagioclase, whereas biotite plates are generally parallel to the concentric banding.

All the orbicules have been deformed, either by flattening or by actual rupture of various parts of the structures. In some specimens parts of concentric bands are isolated in the quartz diorite matrix. Certain of the concentric mineral bands have opened during deformation to form miniature "saddle reefs" which were mostly filled with secondary quartz. The deformation structures are the best evidence that the orbicules crystallized from a fluid medium and were free to move around in a partly consolidated matrix. The

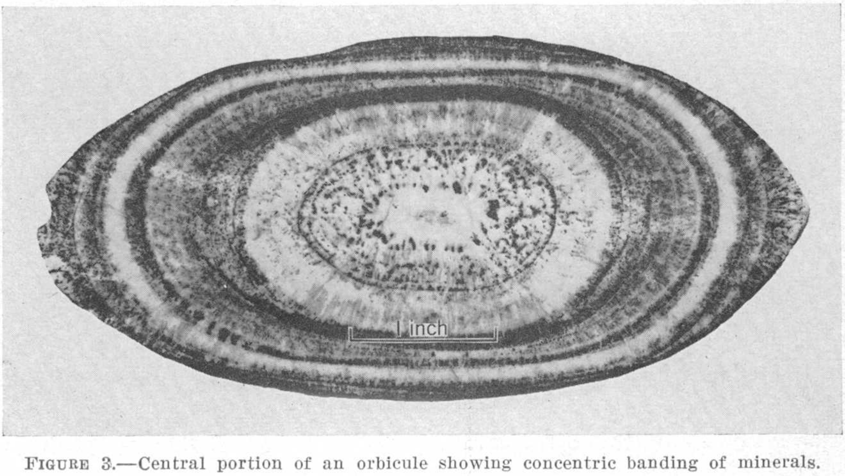

FIGURE 3.—Central portion of an orbicule showing concentric banding of minerals.

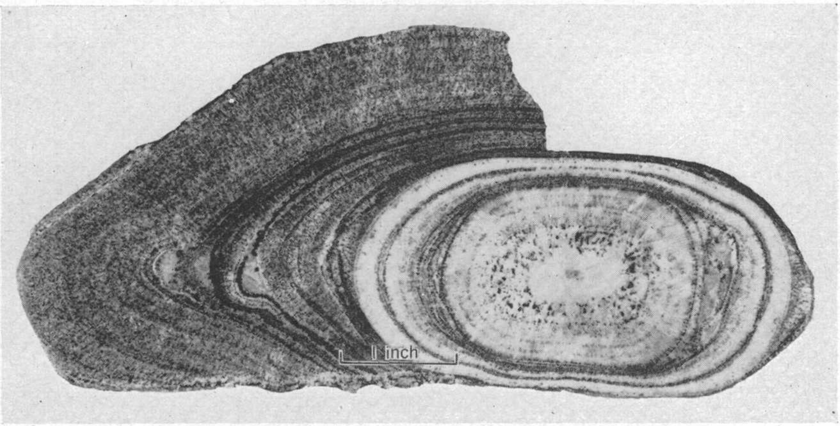

FIGURE 4.—Central portion of deformed orbicule showing "saddle reefs" filled with later quartz.

presence of primary quartz only in the quartz diorite matrix indicates that the orbicules were completely formed before the quartz stage of crystallization—generally considered one of the end phases in the cooling history of an igneous rock—of the host rock was reached.

The orbicular structures have been described in more detail elsewhere and will not be discussed further herein (Ray, R. G., 1952).

GABBRO

In the vicinity of the Lonesome mine 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 plagioclase feldspar and hornblende. 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. Below is a micrometric analysis of the gabbro.

	Percent
Plagioclase	49
Hornblende	48
Accessory minerals	3

A weak zoning is hardly noticeable in the plagioclase, which has an anorthite content of 68 to 72 percent. Multiple twinning parallel to the side pinacoid is common, but twinning parallel to the base is rare. The contrast of anorthite content in the plagioclase of the gabbro and that of the quartz diorite is very strong, but the hornblende of the gabbro is similar optically to that of the quartz diorite.

GRANITE

Granitic rocks have been described from the western part of the Talkeetna Mountains (Capps and Tuck, 1935, p. 102), but such rocks are present only sparingly in the Willow Creek mining 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 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 myrmekite and microcline microperthite have developed.

DIKE ROCKS

GENERAL STATEMENT

In Capps' original discussion of dike rocks in the Willow Creek district it was stated (1915, p. 48) 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 none * * * were large enough to justify their representation on a map of the scale of Plate III [scale is 1: 62,500] * * *

The possible significance of the dikes was not realized, and only brief descriptions of them were given by Capps. J. C. Ray (1933, p. 181), on the other hand, recognized that dike rocks might be of value in locating faulted vein segments, but he made no effort to apply this idea, and no dikes were shown on his geologic map. In the writer's opinion the dike rocks constitute one of the more important geologic features of the mining district because other marker horizons are lacking in the quartz diorite. The productive veins lie almost entirely within the 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. Observations in the quartz diorite alone or in fault zones may yield information regarding the direction of movement along faults, but this information, although valuable, is qualitative only. Detailed surface mapping by the writer has shown that dikes are indeed not abundant, but several have been mapped. (See pl. 1.)

Dike rocks in the quartz diorite may be divided into four general groups: lamprophyre, diabase, aplite, and pegmatite. For the most part only the lamprophyre dikes fall into a recognizable pattern, and they 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 pattern of the major transverse faults 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 will undoubtedly prove fruitful. More precise locating of faulted dike segments by instrument surveys is recomended. Age relations of the various dike types have been determined from scattered observations throughout the district. North of the Snowbird mine diabase cuts an aplite-pegmatite dike, and half a mile south of the Webfoot prospect diabase cuts three lamprophyre dikes. On upper Craigie Creek a lamprophyre dike crosscuts an aplite-pegmatite dike and thus the sequence from oldest to youngest is probably aplite-pegmatite, lamprophyre, diabase.

Movement within the productive quartz veins and along joints containing chalcopyrite-molybdenite and pyrite-stibnite veins is known only in relation to the aplite-pegmatite and lamprophyre dikes. 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. According to J. C. Ray (1933, p. 212), there was no offset of the dike where it was intersected by the vein underground. 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. Regardless of how large the displacement of dikes by movement along the vein fissures might have been, the circumstance would be unique which would prevent dike segments on opposite sides of late major faults from being effective keys to measurement of the major fault offsets. In a few localities where the aplite-pegmatite and lamprophyre dikes do not occupy the strong southwest-dipping joints they are offset by movement along these joints. Thus chalcopyrite-molybdenite and pyrite-stibnite veins which are known to fill these joints are probably younger than the dikes.

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 quartz diorite host. 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 strike is 120° to 140°. The dip is moderate and always to the southwest. Almost everywhere 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 nearly 2,000 feet, and segments belonging to the same dike have been traced for nearly a mile. (See pl. 1.) Offsets by minor faults are numerous. In places the lamprophyre dikes are severed by major transverse faults of the mining district, and it is in this regard especially that they may be of considerable geologic—and hence, economic—importance.

Two varieties of lamprophyre are distinguished microscopically on the basis of grain size. The volume percentages of mineral components indicate that both should be classed as hornblende spessartites.

The first variety is a true porphyry consisting of abundant twinned hornblende phenocrysts as much as 0.2 inch long in a fine-grained groundmass composed predominantly of zoned plagioclase feldspar and some small hornblende crystals. In at least one specimen rhythmic-type zoning was observed in the plagioclase. The feldspar is near An_{50} in composition and appears to be twinned only after the Carlsbad law. Close examination showed a few narrow albite twin lamellae, and universal stage determinations indicated that some crystals are twinned after the albite-Carlsbad law and some after the Carlsbad law alone. Accessory and secondary minerals in the groundmass include sphene, biotite, calcite, deep chestnut-red rutile, chlorite, magnetite, and many long slender needles which may be amphibole microlites.

The second lamprophyre variety is slightly coarser grained than the first and is rather equigranular. Only a few hornblende phenocrysts were seen. These measured less than 0.1 inch in length. Stubby, strongly zoned feldspars with an average composition near An_{50} make up the greater part of the rock. Sodic labradorite forms the cores of the plagioclase crystals and calcic andesine the rims. Carlsbad twinning appears to be prominent; less commonly multiple twins parallel to the base and parallel to the side pinacoid can be observed. Universal stage measurements indicated that the apparent Carlsbad twins are actually albite-Carlsbad complex twins. Twinned hornblende, the chief mafic constituent, is in places altered to chlorite. The groundmass contains magnetite, chlorite, calcite, sphene, amphibole microlites(?), and less commonly biotite, epidote, and zircon.

In all of the lamprophyre dikes the hornblende crystals have a more pronounced needlelike appearance than those in the surrounding quartz diorite; that is, they have a greater index of elongation. It is further observed that the hornblende of the dikes has a weaker absorption and tends to be slightly more of the pale brownish to brownish-green variety than that of the quartz diorite where green and blue-green colors predominate.

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 be differentiated. The diabase is everywhere 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 segment 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 they 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 dikes is due to later shearing along major faults which the dikes occupy.

The term "diabase" is here used for this rock type although the presence of pyroxene, characteristic of the true diabases, can be clearly shown in only a few specimens. Microscopic examination shows a typical subophitic texture. Lathlike crystals of plagioclase feldspar twinned after the albite-Carlsbad law and having a composition of calcic andesine form the bulk of the rock. The original interstitial mafic mineral has been almost completely altered, predominantly to green biotite, magnetite, shredded aggregates of chlorite(?), and calcite. This contrasts with the feldspars which are essentially unaltered with the exception of a few rare phenocrysts. Pyroxene is occasionally seen in very fresh specimens. In a few places the chlorite(?) exhibits outlines which suggest alteration from olivine. A few cores of the olivine(?) remain unaltered, but their small size precludes positive indentification.

APLITE

Aplite 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 dike float has been observed, and it is there that these dikes are most abundant. They do not conform as a rule to any general pattern, although locally they follow the strong southwest-dipping joint set. They typically split, pinch, and swell along the strike, and only rarely can they be traced for more than a hundred feet or so. Both strikes and dips vary radically in many places. Locally these dikes have been useful in marking very minor fault displacements, but it is doubtful that they will ever be of value in correlating movement along major faults of the district. These dikes are usually closely associated with pegmatites in space and are undoubtedly closely related to pegmatites in time. Aplites may occur near, but independent of pegmatite, or the two may form part of the same dike. Where aplite and pegmatite occur in the same dike, the aplite may form the finer grained border and pegmatite the central band; but aplite flanked by pegmatite borders has also been seen.

The aplites are distinguished by their fine grain-size and light-tan to pink color. They generally form only narrow dikes 1 to 4 inches wide, but a few aplite dikes as wide as 5 feet were seen.

Microscopically these dikes are composed essentially of quartz, microcline, orthoclase, and plagioclase. The plagioclase is generally sericitized, but the microcline is unaltered. Graphic intergrowths of quartz and orthoclase are common. Rarely biotite, for the most part altered to chlorite, is present. Apatite, epidote, and a black opaque mineral form the accessory minerals. Secondary calcite forms especially along cleavage planes in feldspars.

PEGMATITE

Like the aplite dikes, pegmatite dikes appear to be more numerous near the southern border of the batholith. The strikes and dips vary radically over short distances, and no dike segments are traceable for more than a hundred feet or so; generally it is much less. Pinching, swelling, and splitting along the strike are characteristic. Consequently the value of these dikes as marker horizons in the quartz diorite, except in small local areas, is dubious. The pegmatites are coarse-grained rocks, associated in most areas with aplite dikes as described above. Dike thicknesses range from about 2 inches to 4 feet. Together with the aplite dikes the pegmatite forms the oldest dike rocks in the area.

Macroscopically, pink feldspar and quartz are the most abundant constituents, euhedral feldspar crystals attaining a length of 3 inches in some dikes. Muscovite or biotite plates half an inch across are present in some specimens, and in a few places slender needles of black tourmaline as much as 1½ inches long occur. Plagioclase is a minor constituent. Recent work has shown the pegmatites to be slightly radioactive owing to small amounts of uraninite, cyrtolite, allanite, and thorite (Moxham and Nelson, 1952).

SEDIMENTARY ROCKS

Sedimentary rocks of Tertiary(?) age, 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. Where the sedimentary sequence is in contact with the quartz diorite the beds are steeply tilted. Southwest of the area mapped the Tertiary(?) rocks are separated from the quartz diorite by mica schist. Study of the Tertiary(?) sedimentary rocks is outside the scope of this paper, and these rocks have been observed only in the vicinity of the Lonesome mine. 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 coarse grained and breaks with great difficulty. It has a striking resemblance to the quartz diorite from which it was undoubtedly derived. Shales and sandstones that 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 batholith as exposed in the Willow Creek mining district is flanked by mica schist of unknown age, and by Tertiary(?) sedimentary rocks composed chiefly of conglomerate, arkose, sandstone, and shale. The petrography and geographic distribution of these rock types have been described elsewhere in this report.

The batholith is roughly 1,500 square miles in extent and is believed to have been emplaced in late Mesozoic time. To the east of the Willow Creek district Paige and Knopf found similar igneous rocks intrusive into Lower Jurassic sedimentary rocks; they also observed boulders of similar igneous rocks in Upper Jurassic sedimentary rocks and therefore concluded that the Talkeetna batholith was Middle Jurassic in age (Paige and Knopf, 1907, p. 20; Capps, 1915, p. 47). It has by no means been shown conclusively, however, that all intrusive rocks in the Talkeetna Mountains and in the related Alaska Range petrographic province to the north are Jurassic in age. Some may be as young as Late Cretaceous (Smith, 1939, p. 90).

Nowhere in the Willow Creek district is the contact between the quartz diorite and mica schist exposed, but comparison of the strike and dip of foliation in the mica schist with that in the nearby quartz diorite suggests that the structures of these two rock types are locally unconformable. (See pl. 2.) 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. The schist is similar in some respects to early Paleozoic or older schist of central Alaska (Smith, 1939, pl. 1; Capps, 1924, p. 92), but the age of the schist in the Willow Creek district is unknown.

About a quarter of a mile southeast of the Lonesome mine the basal conglomerate of the Tertiary(?) sedimentary sequence is in contact with the gabbro of the Talkeetna batholith. Here the bedding is steeply tilted to the south at angles ranging from 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 Tertiary(?) 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. It seems plausible that the sedimentary rocks were derived, in part, from the solid roof of the batholith and that there was a later uplift of the solidified portion of the intrusive mass, imparting a steep tilt to the sedimentary rocks. The original Tertiary age determination of the sedimentary sequence, based on the interpretation of fossil plants collected by Paige and Knopf (1907, p. 26) in 1906 and by Martin and Katz (1912, p. 42) in 1910, is questionable, however. The plant remains were considered to be Eocene in age. Recent paleobotanical studies have shown the need for revision of many Cretaceous and Tertiary age determinations of Alaskan fossil plants, and the sequence here considered Tertiary(?) may be Cretaceous or older. A pre-Eocene age has also been suspected from recent geomorphological studies.

STRUCTURAL FEATURES OF THE QUARTZ DIORITE

FOLIATION

Megascopic foliation due to primary mineral orientation is generally moderately well developed in the quartz diorite. It has a rather constant trend to the northeast and moderate dip to the northwest (pls. 2 and 3), and is most easily seen where hornblende is the prominent mafic mineral. In those areas where hornblende is better developed than biotite the foliation is easily measured, but where biotite is seemingly more abundant the foliation is difficult to measure. Biotite has commonly formed in rather equidimensional books and a planar orientation of this mineral is only seldom observed. Thus in areas where large biotite books are common, few foliation measurements have been recorded. In a few places a strong preferred orientation of hornblende within the primary flow planes gives rise to a second, but weaker planar structure at a large angle to the primary planar structure.

Linear structures in the quartz diorite batholith are measured only with much difficulty, but some observations have been made on the plunge of hornblende prisms and long axes of inclusions. These lineations generally strike to the north and plunge on the average about 40° in that direction (pl. 2). Extremes in plunge are 4° and 70°. Intersections of primary flow layers with the weaker planar structure described above also form a lineation which conforms in general to the hornblende lineation and plunge of long axes of inclusions. In most places the lineation lies in the foliation plane; but lack of natural surfaces parallel to the foliation planes makes observations of such linear structures difficult. All joints cut the foliation; none are parallel to it. Determination of lineations in the quartz diorite by structural petrologic methods is impractical because of the medium grain-size of the rock.

INCLUSIONS AND SEGREGATIONS

Inclusions in the quartz diorite are exceedingly common. They comprise at least three different rock types that 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 commonly stand out in relief above the quartz diorite host. Where they stand out in relief, the elongation direction can sometimes be observed to give a lineation. These inclusions range from about 1 inch to as much as 5 feet in length.

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Most are 1 to 2 feet long, however, and are but a few inches wide. A few of the inclusions appear to be stretched out at their ends, and foliation in the quartz diorite flows around most of them conformably. Some have frayed ends and show tongues of quartz diorite penetrating into them; but the ends of most are blunt and rounded. Although most of these structures lie in the foliation planes of the quartz diorite a few definitely cut across the foliation. In some places larger inclusions are fractured and quartz diorite now separates the broken sections. Contacts between these inclusions and the host quartz diorite are generally sharp, but locally there occur narrow somewhat mixed zones showing an intermediate color and grain-size. In places a boudinage type of structure is developed in some of the more elongate inclusions.

Mineralogically the small mafic inclusions are somewhat similar to the quartz diorite host. Plagioclase and hornblende phenocrysts are usually present in a groundmass of essential plagioclase, hornblende, and biotite. Apatite, magnetite, and sphene are common accessory minerals. Zircon is present rarely. The plagioclase phenocrysts are strongly zoned and range from 37 to 48 percent anorthite in composition. Groundmass plagioclase in some specimens has the same range in anorthite as the phenocrysts, but in general it is slightly more sodic. The total quantity of biotite and hornblende is greater than in the quartz diorite host, and quartz is almost always lacking. A micrometric analysis of a fine-grained inclusion from the main haulageway of the Fern mine showed the following mineral percentages:

	Percent
Plagioclase	65
Hornblende	19
Biotite	14
Accessory minerals	2

This inclusion is typical and indicates that this rock type is diorite.

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 or 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 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 altitudes 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 thickness of 3½ to 4 feet. It is a tabular body essentially horizontal and parallel to the foliation in the surrounding host rock. The third dimension was not determined. 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. The dark bands contain more hornblende and biotite than the light bands, but less quartz. Contacts between individual bands are undulose but mostly sharp. The plagioclase is weakly zoned and ranges from 35 to 37 percent anorthite in composition. These large mafic inclusions differ generally from the smaller ones described above in that they are finer grained, nonporphyritic, commonly banded, and contain quartz. Rarely one of the smaller mafic inclusion types is fine and even grained, but quartz is not a constituent.

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 prominent mafic mineral. The schlieren are typically black owing to the concentration of biotite and particularly hornblende. Most schlieren are coarser grained than the surrounding quartz diorite but are mineralogically similar, differing only in the relative abundance of various minerals. The plagioclase ranges from 41 to 47 percent anorthite and is thus comparable to that in the quartz diorite. Quartz is likewise a constituent of the schlieren.

Mafic schlieren may be present as thin bands 2 or 3 inches wide and several feet long. These are concentrations of hornblende crystals forming bands parallel to the foliation of the quartz diorite. More commonly the schlieren are irregular masses or lenses locally as much as 10 to 20 feet long and 5 or 6 feet wide. They may exhibit a strong foliation and this is generally parallel to the contact of the schlieren with the quartz diorite. In most places the contact of the schlieren mass cuts across the foliation of the quartz diorite, often at a large angle. Small mafic inclusions may be present in the schlieren as well as the enclosing quartz diorite. Such inclusions within the schlieren generally lie parallel to the foliation of the schlieren, but in a few places they are parallel to the foliation of the quartz diorite.

Schlieren of light-colored minerals, predominantly quartz and feldspar, are present to a much lesser extent. No microscopic examination has been made of them.

JOINTS

Three joint sets characterize the quartz diorite except for a zone about 1 mile wide, parallel to and immediately adjoining its southern border where only a few joints occur and conform to no definite pattern (pl. 3). In any one area only 2 of the 3 joint sets may be conspicuous, but throughout the quartz diorite area the southwest-dipping set of joints is always prominent. The average strike of this set is 135°, although the strikes range from about 170° in the eastern part of the mining district to about 095° in the westernmost part of the district; the dip is about 40° to 45° SW. These joint surfaces are often developed over many tens of feet and in general are remarkably smooth and flat. In some areas they are nearly perpendicular to the lineation of hornblende crystals and long axes of inclusions, but in general although they are at a considerable angle to the lineation they are not perpendicular to it and do not qualify as cross-joints. They may be further characterized by a barren quartz filling 1 to 4 inches wide, and in many places they are the site of chalcopyrite-molybdenite veins, and aplite and lamprophyre dikes. The second joint set trends generally just west of north and dips steeply to the east. In the western part of the mining district, however, the strike is nearly due west and the dip north. These joints are strongly developed locally and often exhibit regular surfaces over many feet. A third joint set ranges in strike from nearly due east to northeasterly; in general dips are steep either to the northwest or southeast. This third joint set is poorly developed and characteristically shows irregular surfaces.

The spacing of joints varies from place to place. Commonly 10 to 20 feet separate joint planes, but over small areas joints may be as little as 1 foot apart. In general, wide spacing (6 to 10 feet) predominates, however, and gives the quartz diorite terrane a rugged, blocky appearance.

As in all igneous bodies there are joint planes in the Willow Creek area that do not fit the general pattern, but they are minor in number. At the head of Craigie Creek several low-dipping joints have formed, and this led J. C. Ray (1933, p. 186) to postulate that certain quartz diorite blocks between major faults had been rotated. Careful observations and the plotting of hundreds of joint measurements by the writer show that the strikes and dips of the joint sets described above vary slightly but consistently over an area cut by several major faults. (See pl. 3.) Unless the rotation of fault blocks were considerable, it is doubtful that the joint pattern would be a valid basis for postulating hinge movement of such blocks.

Although the southwest-dipping joints may very locally appear to have exerted control on the emplacement of certain of the productive gold quartz veins, such joints are not the loci of the productive veins as described by Capps (1915, p. 56). Where quartz veins are parallel to the southwest-dipping joints prospecting may be expected to be unprofitable.

FAULTS

A variety of faults with displacements ranging from a few inches to a few hundred feet cut the quartz diorite (pl. 1). The major faults of large displacement divide the quartz diorite into a number of blocks in which productive gold quartz veins are confined. These faults 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 post-ore faults trend northwestward and dip predominantly to the northeast. They are believed to be mostly of normal displacement and are distinguished by 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. Displacements on these major post-ore faults are all believed to be large, but in only a few places is the amount of offset known. Faulted segments of the rich Gold Bullion vein have never been found, but if the post-ore faults are normal faults, the southern extension of the Gold Bullion vein would have been thrown above the present erosion surface, and hence would now be eroded away. Extensions of the Gold Bullion vein to the north would have been thrown down, and should therefore be present in the valley of upper Willow Creek or on the slope northwest of the stream. Inaccessible prospect tunnels on the slope between the Gold Dust and Martin faults (on property formerly known as the Jap prospect) are reliably reported to have penetrated a quartz vein that yielded assays high in gold. The position of the vein has also been explored by diamond drilling. The interesting speculation exists that this vein may represent a faulted northward extension of the Gold Bullion vein and may also represent the westward extension of either the Independence vein or Skyscraper vein south of the Martin fault (see also p. 63).

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 somewhat more than 300 feet. To the east it is displaced about 250 feet by a second post-ore fault. Likewise, 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 Mabel fault is about 150 feet, and according to J. C. Ray (1933, p. 211) the horizontal component of displacement on the fault in the east end of the Lucky Shot mine is more than 600 feet. Although the total offset on the major post-ore faults has been 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 profitably minable quartz vein was reported to lie in part within the Martin fault. Thus there is some evidence that the greatest 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 undertaken in an attempt to determine the quantitative displacement of various faults. No dikes have been traced with certainty across the wide, northwestward-trending post-ore fault zones, but the positions of lamprophyre dike segments in the vicinity of the Lucky Shot mine and on the ridge south of the Gold Bullion mine (pl. 1) are strong evidence that the major faults are normal faults. Many narrow faults, commonly striking northeastward and having displacements as great as 200 feet, have been mapped and a general pattern of displacement established. With few exceptions the displacement of dike segments north of these narrow faults has been relatively to the east and probably downward. (See pl. 1.) The same pattern probably holds for the major faults, so far as can be inferred from surface and 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. These faults trend nearly due north, the same as the gold quartz vein, but most dip to the east, in a direction opposite to that of the vein. The mine record shows that strike faults exposed on the 300 level are hinge faults of normal displacement. Displacement increases to the north. In contrast to the wide northwestward-trending fault zones, strike faults are mostly only a few inches wide. Two strong strike faults are also known in the Independence mine, but they 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 (figs. 5 and 6). The relation of aplite dikes to the vein at the Mabel mine indicates that movement in the plane of the vein was reverse. Stoll (1944, p. 205) reports that shearing has caused a slight reverse displacement along the Independence vein.

DEVELOPMENT OF FRACTURE PATTERNS

At least three well-established fracture patterns are recognized in the quartz diorite of the Willow Creek mining district. These are: (1) a joint system consisting of a conjugate pair of joints and a rough set of joints generally perpendicular to the intersection of the conjugate pair; (2) the gold quartz veins, which may be represented as a pair of conjugate shear planes; and (3) the post-ore faults. In the

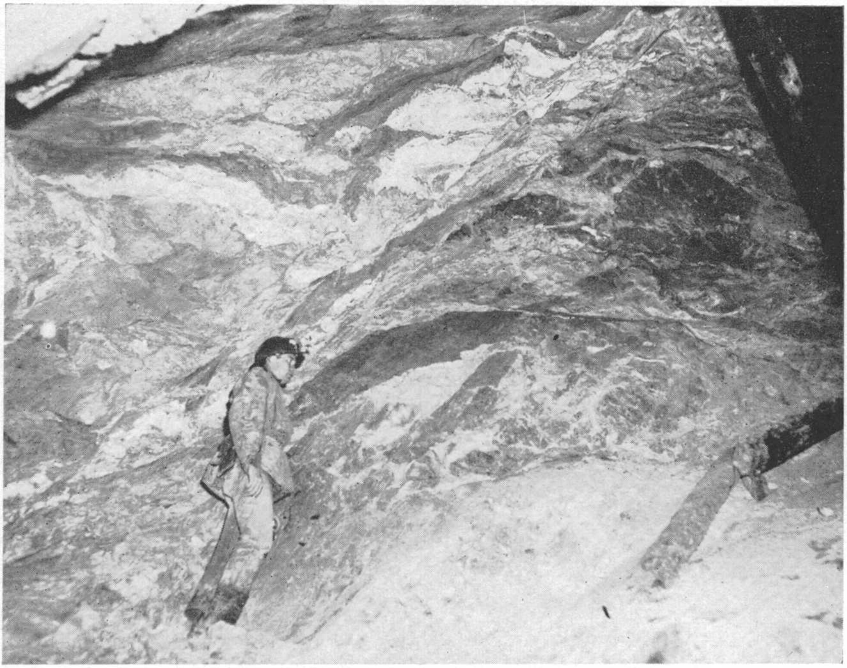

FIGURE 5.—Fern vein showing contorted quartz lenses in clay gouge and sheared quartz diorite. Zone is about 17 feet wide.

FIGURE 6.—Snowbird No. 3 vein showing contorted quartz lenses in clay gouge and sheared quartz diorite. Note similarity to Fern vein.

eastern part of the mining district the joints of the conjugate pair strike generally just west of north. One set dips to the northeast; one set dips to the southwest. In the western part of the mining district the strikes of these joints have shifted gradually to nearly due west. The rough set of joints perpendicular to the conjugate pair likewise has shifted in strike from nearly due east in the eastern part of the mining district to northeasterly in the western part of the district. These rough joints dip vertically or steeply to either side. The shear planes forming the productive gold quartz veins include one set trending nearly due north, dipping from a few degrees to about 45° to the west, and one set trending 060° to 080°, dipping 30° to 60° N. Prominent post-ore faults strike northwestward and dip predominantly to the northeast. It is not known whether the post-ore faults penetrate the schist to the south, but field investigations have shown that the joint pattern and quartz-vein pattern do not extend into the schist. Consequently it is believed that the fracture systems are a direct manifestation of the internal tectonics of the quartz diorite batholith rather than of a regional deformation plan. Detailed mapping of all structural elements in the batholith margin was carried out in an attempt to relate the fractures to the tectonic pattern of the intrusive mass. Although such a genetic relationship of the fractures to the batholith intrusion is strongly suspected, it has not yet been possible to demonstrate this convincingly.

The prominent southwest-dipping joints, commonly the loci of barren quartz veins, lamprophyre, aplite, and pegmatite dikes, were originally believed to be tension joints, and an attempt was made to relate them genetically to the intruding magma on this basis, considering at the same time the formation of the major shear zones containing the gold quartz veins. With this assumption the two fracture patterns can be related to the intruding magma only by assuming an upward movement of the magma parallel to a moderate northeasterly-plunging lineation which initially represented a direction of tension but which became a direction of shearing stress at some latter stage in the consolidation of the quartz diorite. Such a relation of lineation to first a tension and then a shear direction may be valid, but it would account only for the southwest-dipping set of joints and would not explain the other two joint sets.

If the mineralized southwest-dipping joints are not considered as tension joints but rather as the open shear of a conjugate set developed by a rotational shearing stress, then all three joint sets in the quartz diorite can be related to a hypothetical shearing stress acting upward at a moderately steep angle from the northeast quadrant. The southwest- and northeast-dipping joints would represent the conjugate shear planes. The rough, steeply dipping joints might form from tensional relief in a direction perpendicular to the intersection of the conjugate shear planes. If part of the tensional stress were relieved along the conjugate shear planes (i. e. the southwest- and northeast-dipping joints), then slickensides plunging gently to the southeast or northwest might be expected to develop on one or both of them. The observation of such slickensides particularly on the southwest-dipping joints perhaps bears out the conclusion that the rough, steeply dipping joints might have formed by such tensional relief.

Although there is no proof that shearing stresses acted upward from the northeast quadrant, it may be significant that such stresses, although at slightly different angles, could have been responsible for the development of the productive shear zones as well as the joint system, and further that many lineations in the quartz diorite strike just east of north and plunge gently to moderately in that direction. It seems quite probable that the lineation direction, initially a direction of tension, could have been nearly parallel to a direction of shear at a late stage in the consolidation of the quartz diorite batholith. The presence of northerly- to northeasterly-plunging lineations in the flow planes of the quartz diorite suggest that shearing stresses from a general northeasterly direction may have existed. Although a hypothetical rotational shearing stress acting upward at a moderate angle from the northeast quadrant could have formed the productive shear zones, in the absence of any structural detail to validate such a hypothesis it must be recognized that a nearly horizontal direct compression from the northeast quadrant could also have been responsible for the development of the shear zones. So far as can be determined from field data there is no conclusive evidence for relating the productive shear zones, either alone or together with one or more joint sets, to primary structural elements of the quartz diorite at the batholith margin. Study of a larger area along the batholith front may demonstrate a genetic relationship between fracture patterns and primary elements of the quartz diorite.

The post-ore faults are visualized as having formed in the upper solidified portion of the quartz diorite mass due to a doming effect resulting from late movement deep in the magma chamber where crystallization was not yet complete.

ECONOMIC GEOLOGY

GENERAL HISTORY AND PRODUCTION

Lode gold was first discovered in the Willow Creek district in 1906 on upper Fishhook Creek. Considerable activity followed this discovery and several properties came into production in the next few years. Early mining was handicapped by the problem of supply in an area that had almost no roads and was yet to see the construction of the Alaska Railroad. Most materials were freighted into the district by horse. Despite these conditions several small stamp mills were set up on various properties and active mining flourished. Completion of the Alaska Railroad shortly after World War I, and the construction of roads into the mining district, made many areas much more accessible, and heavier equipment could be brought in more easily. No large mines are yet in operation in the Willow Creek district, however, but the small mines are generally well equipped. Ball mills have replaced the old stamp mills, and other modern equipment has been installed.

Individual mine histories show a record of successes and failures over the period of active mining during which somewhat less than $18,000,000 in gold has been produced (table 6). Gold production in the district was at its peak between 1931, shortly before the price of gold was increased and the closing of all gold mines soon after the beginning of World War II. Since the end of the war some mines have resumed operation, but production has been small in comparison with that of pre-war years.

TABLE 6.—*Lode gold production by years*

Year	Value [1]	Year	Value [1]
1909	$13, 751	1931	$459, 000
1910	21, 630	1932	709, 000
1911	53, 662	1933	776, 000
1912	100, 000	1934	1, 391, 000
1913	100, 958	1935	620, 000
1914	297, 184	1936	705, 000
1915	247, 267	1937	888, 000
1916	299, 193	1938	1, 163, 000
1917	195, 662	1939	1, 338, 000
1918	269, 624	1940	1, 858, 000
1919	162, 944	1941	1, 686, 790
1920	63, 400	1942	1, 314, 215
1921	118, 273	1943	457, 765
1922	238, 000	1944	134, 365
1923	178, 238	1945	64, 610
1924	201, 878	1946	44, 625
1925	454, 581	1947	12, 530
1926	334, 000	1948	16, 765
1927	158, 000	1949	177, 485
1928	104, 000	1950	304, 534
1929	12, 000		
1930	36, 000		17, 780, 929

[1] Figures for value of gold produced between 1909–1937 taken from U. S. Geol. Survey Bull. 917–C; for 1938, U. S. Geol. Survey Bull. 917–A; for 1939, U. S. Geol. Survey Bull. 926–A; for 1940, U. S. Geol. Survey Bull. 933–A; for 1941–1950, U. S. Bureau of Mines, Economics Division.

VEINS

GENERAL STATEMENT

Excluding pegmatites, which in places contain minor amounts of chalcopyrite and bornite, the veins may be divided structurally into two groups, an older group generally conforming to the strike and dip of southwest-dipping joints and a younger group occupying major shear zones in the quartz diorite. Veins along the southwest-dipping joint planes are nonproductive. They can be subdivided into three types on the basis of mineral content. The most common type is composed of chalcopyrite, pyrite, arsenopyrite, molybdenite, 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. The quartz bodies in the shear zones comprise the productive veins of the district. They are subdivided into two groups, one trending 060° to 080°, dipping 30° to 60° N., and one trending nearly due north, dipping from a few degrees to about 45° to the west.

VEINS PARALLEL TO THE SOUTHWEST-DIPPING JOINTS

CHALCOPYRITE-MOLYBDENITE VEINS

By far the most abundant veins in the district are vuggy, glassy quartz veins characterized by chalcopyrite and molybdenite but also containing pyrite and arsenopyrite. They stand out distinctly owing to the blue and green colors of azurite and malachite that have resulted from surface alteration of chalcopyrite. Limonite staining is also prominent on many 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° SW. Much of the quartz is somewhat sheeted, and the 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(?).

PYRITE-STIBNITE VEINS

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 from the chalcopyrite-molybdenite veins is not certain, but it may be significant that no specimens have been found showing molybdenite and stibnite associated in the same vein. The pyrite-stibnite veins are similar in size to the chalcopyrite-molybdenite veins but are far less common.

NONPRODUCTIVE GOLD QUARTZ VEINS

In a few places vuggy quartz veins trending with 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 was deposited as coarse plates around quartz crystals. On the ridgetop east of the Gold Cord mine upper workings two other quartz veins containing sparsely distributed gold are found in southwest-dipping joints. These small veins intersect an eastward-trending vein that conforms to the productive vein pattern, although the gold-bearing, eastward-trending vein has not yet proved to be of commercial importance. Gold in veins occupying joint openings is uncommon; where it is present it may suggest the proximity of a vein of the productive-vein pattern.

PRODUCTIVE GOLD QUARTZ VEINS

DISTRIBUTION AND ATTITUDE

Productive gold quartz veins of the Willow Creek mining district occur in shear zones that 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 an easterly direction and about 4 miles wide. In general, the productive veins fall into two groups: one trending 060° to 080° and dipping 30° to 60° N., 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 includes some carbonate and small amounts of pyrite, arsenopyrite, sphalerite, chalcopyrite, tetrahedrite, nagyagite, altaite, coloradoite(?), 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 quartz 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 that are as much as 25 feet wide in some places. The quartz may have a sugary texture and usually occurs in long lenses, aggregates of small lenses, or branching quartz stringers a few inches wide (fig. 5). In places slickensided blocks of partly altered country rock together with sticky clay gouge make up much of the zone.

The north-trending ore bodies, on the other hand, often form well-defined veins, and in places quartz fills the entire width of the shear zone. Quartz widths of 6 feet are not uncommon, and a few zones much wider than this have been reported. Commonly 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 (fig. 7). 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 down the dip and pass into barren parts of the shear zone composed only of broken and altered quartz diorite fragments. One or two exceptional areas have been reported where shear zone material was actually productive.

Quartz varies from gray to blue gray to milky white, and may or may not be banded. In a few places veins occur which appear to be in the pattern of productive veins, but which have not yet proved productive themselves. These are characterized by fairly coarse

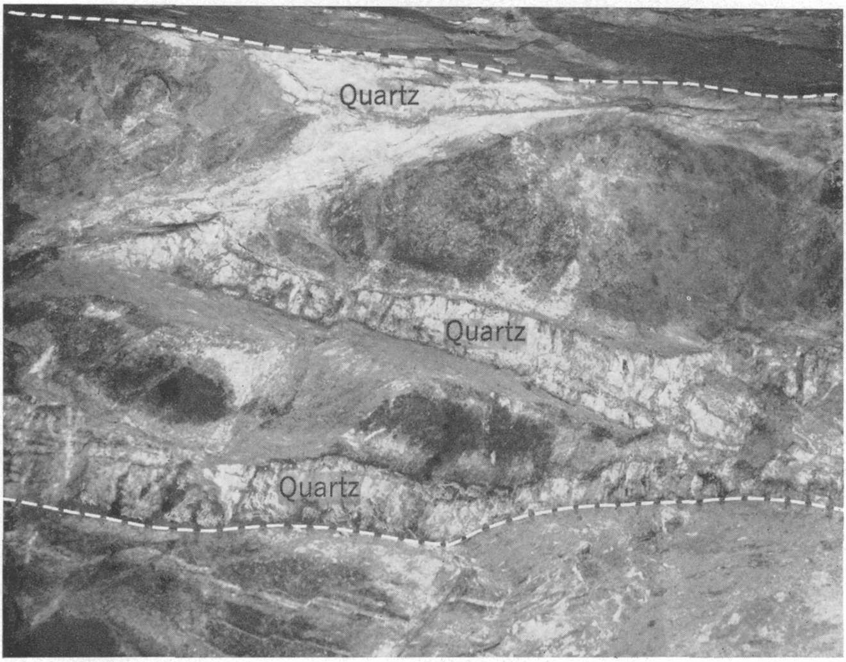

FIGURE 7.—Hanging-wall vein No. 2, Fern mine, showing branching nature of quartz bands Width of zone is about 4 feet.

vuggy quartz. Small flakes of gold have been seen in some specimens from these veins, and assays as high as $1,000 have been reported. Quartz in productive veins generally contains few or no vugs but is badly sheared.

Banding in the quartz stands out clearly in many thin sections. Layers of very fine grained quartz alternate with bands of slightly coarser grain. The coarser grained bands in places show elongate clear quartz crystals with well-developed terminations on one end; these are believed to represent open-space filling. Late carbonate filling around terminated quartz crystals has been observed in many specimens (fig. 8), which suggests that open spaces may have existed for some time. Quartz aggregates commonly exhibit numerous small fractures. These may follow grain boundaries as well as cut across individual grains, and may be filled with either aggregates of carbonate, fine-grained quartz, or sericite. Branching and crisscrossing carbonate stringers are conspicuous, particularly in some fine-grained bands. Quartz of some of the coarser grained bands is generally remarkably free of strain shadows and undulatory extinction. This suggests that at least certain bands were not deformed by the shearing

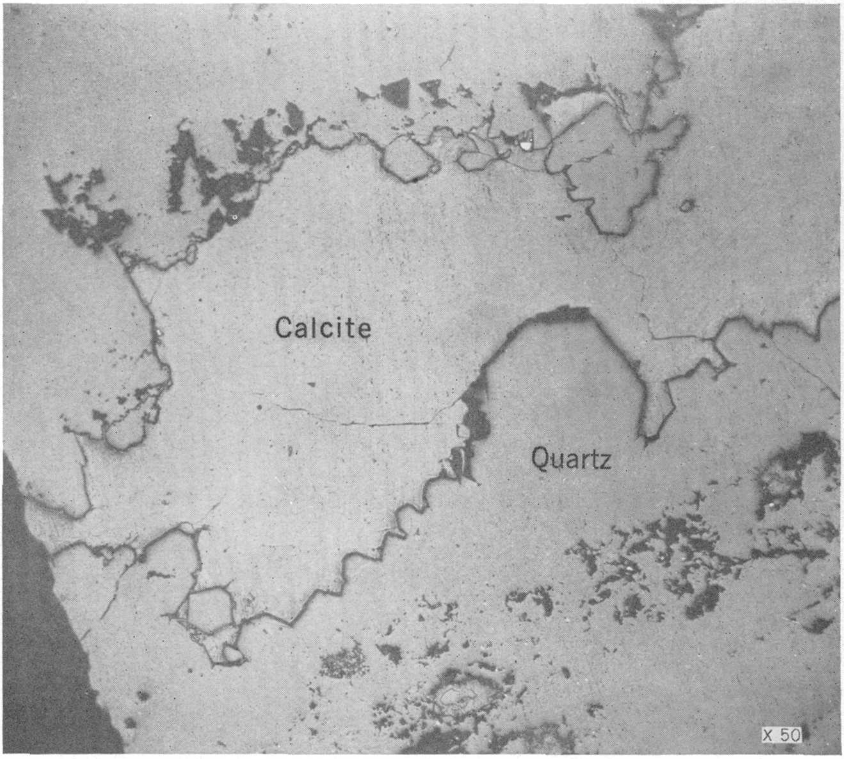

FIGURE 8.—Photomicrograph of early formed quartz crystals and late calcite.

stress which was active from time to time in the planes of the veins.

Quartz microbreccia is common throughout the veins, and microbrecciation has been suggested as a mechanism that 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 that 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. It has also been noted that quartz in a microbreccia zone was filled with randomly oriented, hairlike inclusions similar to those found in the quartz of the original quartz diorite. This quartz may represent quartz of the original country rock which has been ground up in the shear zone.

MINERALOGY AND PARAGENESIS OF THE ORE

The ore of this district is essentially a free-milling gold quartz ore containing small amounts of sulfides, estimated to be about 2 or 3 percent by weight. Small quantities of tellurides are present locally. J. C. Ray (1933, p. 191) reported the gold to be about 950 fine. So far as can be determined from polished specimens, binocular study of hand specimens, and heavy mineral separations, the variety of ore minerals 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 and was undoubtedly deposited throughout a long period of time. At least two generations of quartz are known and others may be present. 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 (fig. 8). It is common to find elongate, terminated quartz crystals, which formed in open cavities, now surrounded predominantly by carbonate and to a lesser degree, by late quartz and sulfides.

Scheelite is present sparingly in most of the productive veins. It appears to be restricted to the early quartz [2], but its position in the paragenetic sequence is otherwise not known with certainty.

Pyrite is the most abundant sulfide, occurring as striated cubes, pyritohedrons, and irregular grains. Within the veins it is restricted

[2] Gates, G. O., 1942, Scheelite deposits in the Willow Creek district, Alaska: Unpublished War Minerals report in files of U. S. Geol. Survey.

for the most part to the earlier quartz. It was the first sulfide deposited. Most pyrite grains are typically fractured, and the larger fractures commonly are filled with late carbonate, rarely with quartz. Nagyagite, chalcopyrite, and gold have also been observed as fracture fillings in pyrite.

Sphalerite was seen only in a few specimens. It occurs in places 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 almost completely, surrounded by a narrow fringe of chalcopyrite (fig. 9). This latter relationship suggests that sphalerite deposition was closely followed by chalcopyrite. During the cooling of sphalerite, and perhaps contemporaneously with the chalcopyrite fringe deposition, small blebs of chalcopyrite exsolved from it giving the sphalerite a somewhat distinctive appearance, although no exsolution pattern is conspicuous. 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 (fig. 10) and was probably the next sulfide to be deposited after sphalerite (fig. 9). Its position with respect to tetrahedrite is fairly well established (fig. 9). 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 have formed directly in the sphalerite and chalcopyrite, but in general tetrahedrite seems to have followed the deposition 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 probably contained in the tetrahedrite or coloradoite(?). Although cinnabar is occasionally found in similar gold quartz veins in other mining districts, none was seen in the Willow Creek veins. Prospectors' reports of cinnabar in these veins, however, may have a measure of support in the spectrographic identification of mercury.

Perhaps the most important discovery resulting from a study of the Willow Creek ores is the positive identification of tellurides. Tellurides have been reported in the past but never identified. An earlier report of tellurides at the Lucky Shot mine (Smith, 1932, p. 18) was checked by J. C. Ray (1933, p. 191–192), who reported no tellurium in the sample analyzed. The present study has shown that in some

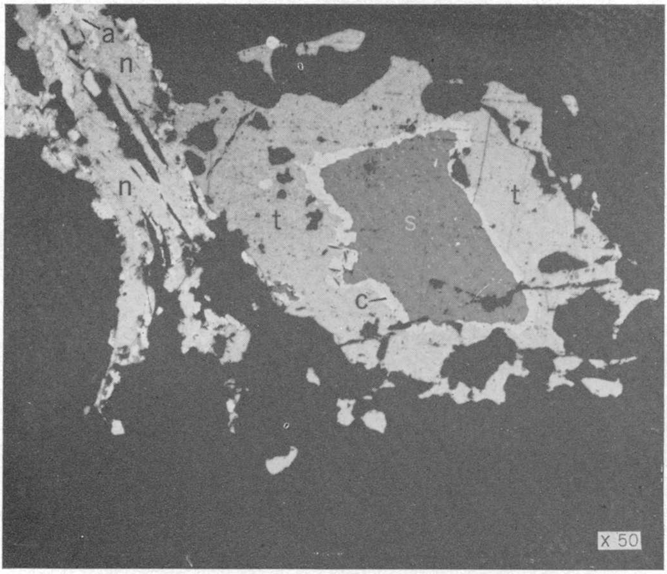

FIGURE 9.—Photomicrograph of sphalerite (s) surrounded by chalcopyrite (c), which, in turn, is enclosed by tetrahedrite (t). Closely associated is nagyagite (n) and altaite (a).

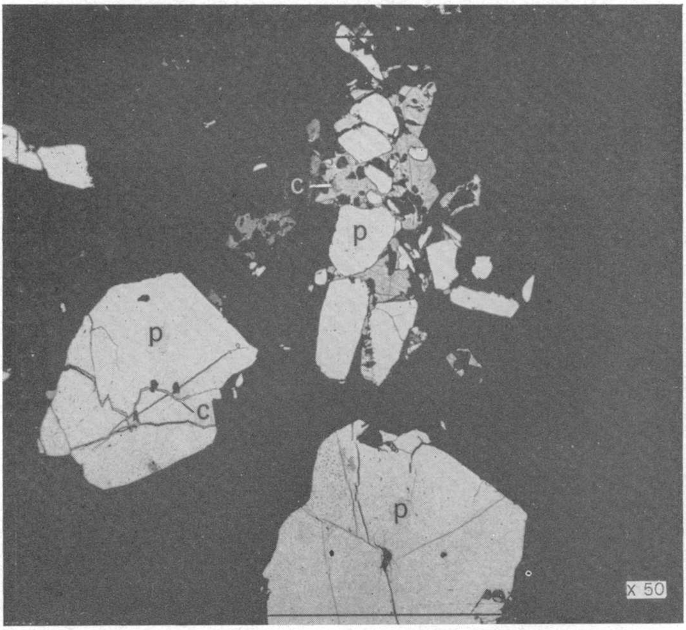

FIGURE 10.—Photomicrograph of chalcopyrite (c) surrounding and filling fractures in pyrite (p).

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ore at the Fern mine and at the Schroff-O'Neil mine nagyagite, a black-colored 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 (fig. 11), and the paragenetic relationship is difficult to determine. Binocular examination of some ore samples shows plates of gold largely surrounding nagyagite, implying a younger age for the gold. But from polished-section study the possibility of contemporaneous deposition at least in part is suggested. In some specimens nagyagite occurs associated with euhedral quartz, which suggests open-space filling around earlier quartz. In other places nagyagite fills fractures in earlier pyrite (fig. 12). 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 (fig. 13). The nagyagite, altaite, and gold appear to be very closely related in age and were undoubtedly among the latest metallic minerals to be deposited. A pink isotropic mineral—possibly coloradoite, the telluride of mercury—is present sparingly.

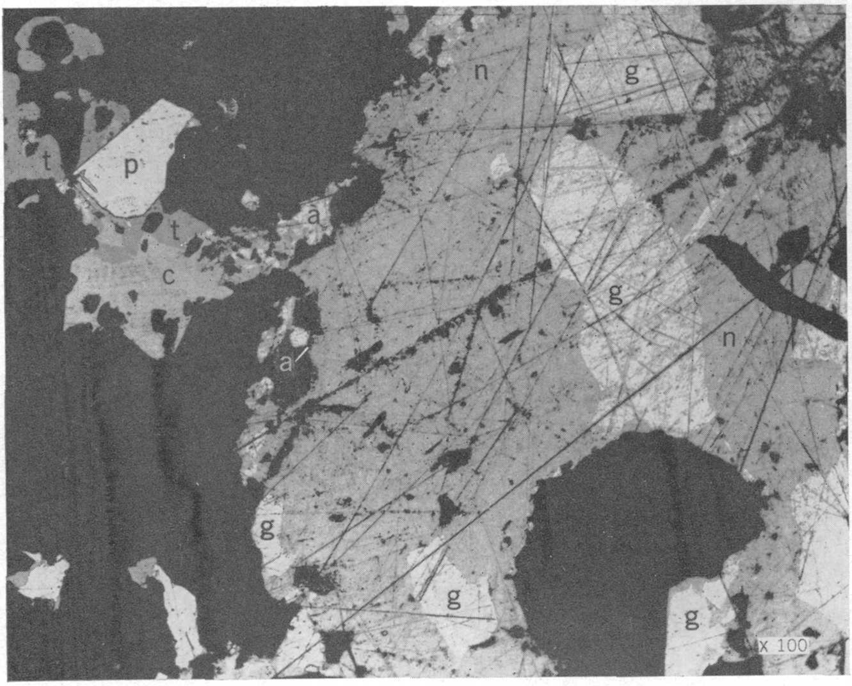

FIGURE 11.—Photomicrograph of gold (g) in nagyagite (n). Altaite (a), chalcopyrite (c), tetrahedrite (t), and pyrite (p) are also associated minerals in this specimen.

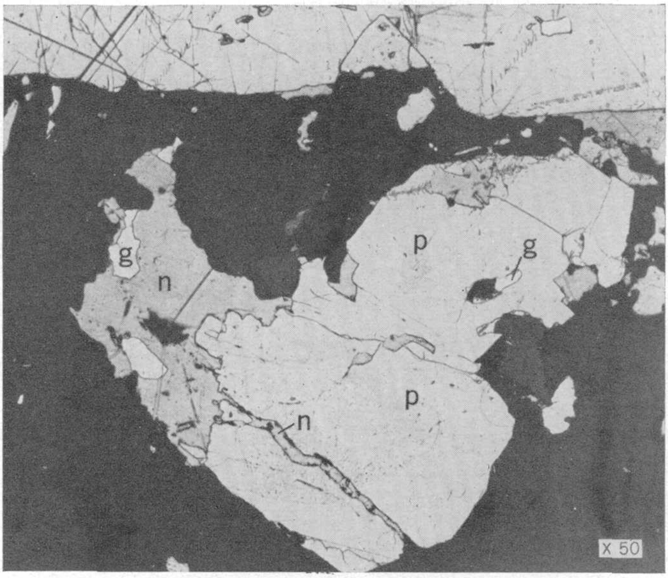

FIGURE 12.—Photomicrograph of nagyagite (n) filling fractured pyrite (p). Gold (g) is present in both nagyagite and pyrite.

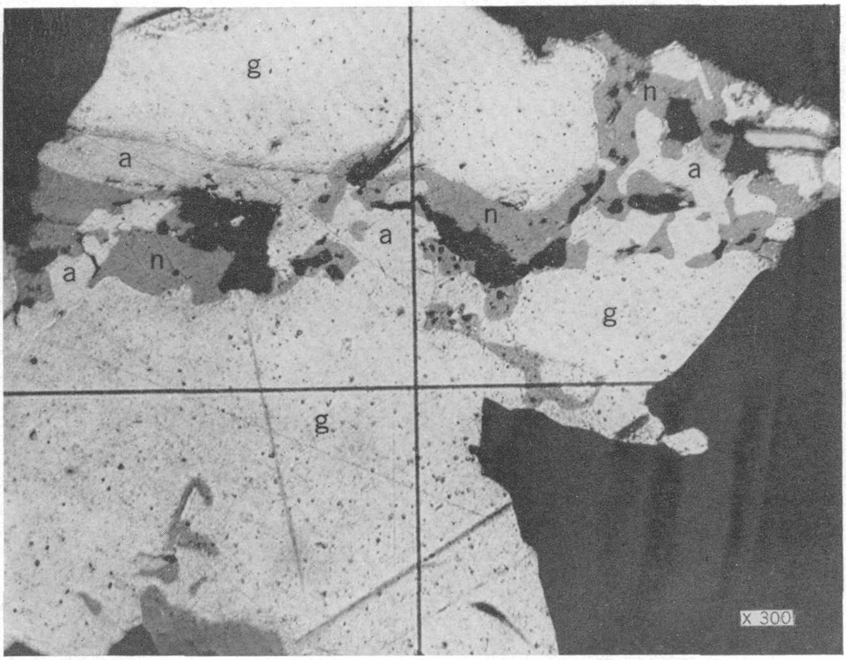

FIGURE 13.—Photomicrograph of altaite (a) in nagyagite (n). Gold (g) is also associated.

Galena has been identified in only a few specimens where it occurs in masses that exhibit good cubic cleavage. X-ray diffraction patterns indicate galena to be present in some specimens where microscopic identification could not be made. The study of polished sections shows that it is not an important sulfide in the ore. Gold is usually closely associated with the galena cubes as flakes either 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 certainty.

Arsenopyrite is a conspicuous sulfide occurring as large individual grains or in cruciform twins, but nowhere was gold seen in direct association with it, although J. C. Ray (1933, p. 190, 192) has reported gold replacing it.

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.

Gold from 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 thousands of an inch in width. Gold occurs as isolated flakes or blebs strung out within the quartz, and in a few places as

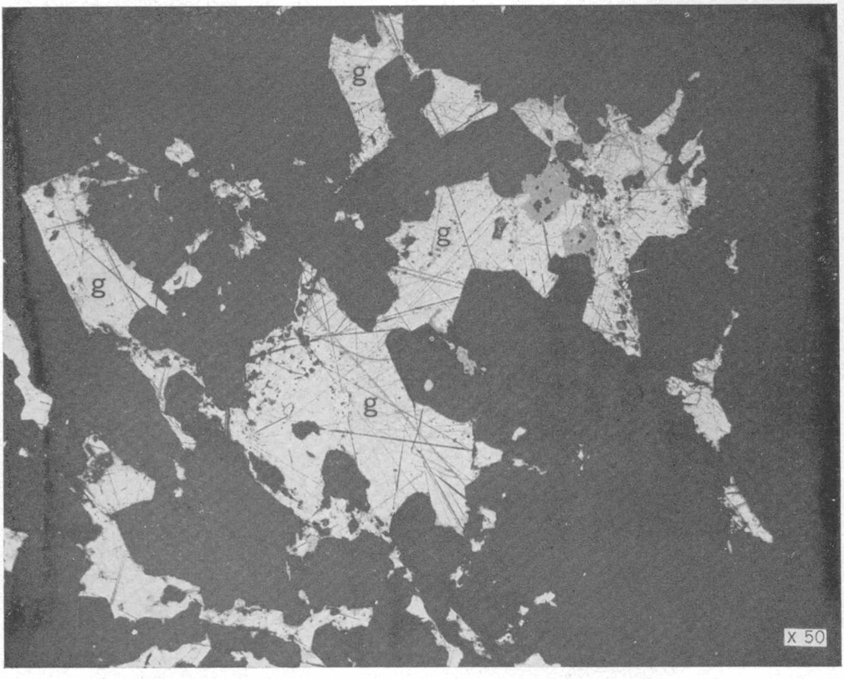

FIGURE 14.—Photomicrograph of gold (g) in quartz (black). Note angular relationship in places suggesting deposition of gold in open spaces around early euhedral quartz crystals.

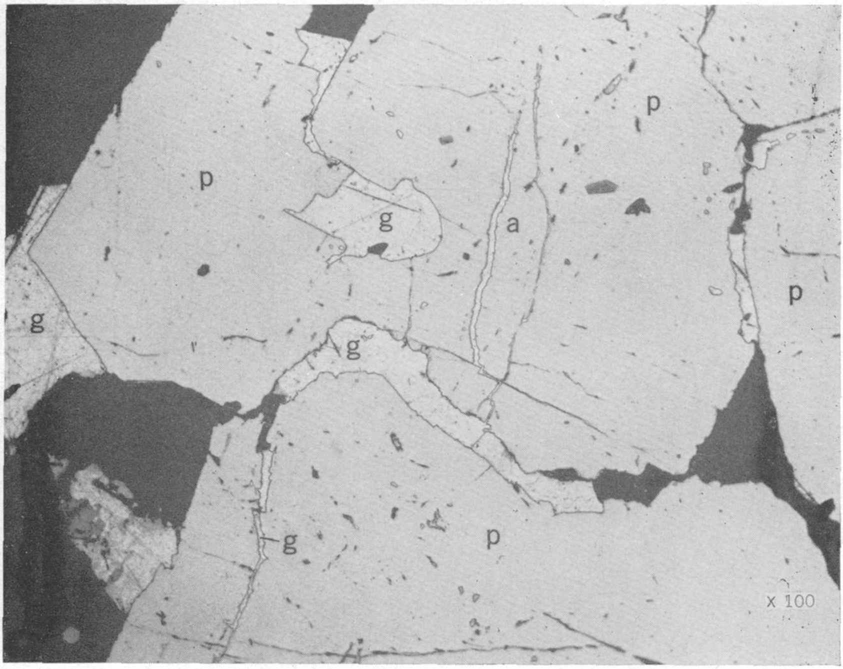

Figure 15.—Photomicrograph of gold (g) filling and replacing older pyrite (p).

fillings around early euhedral quartz crystals (fig. 14), but commonly it is 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 (fig. 15). Aside from this relationship, in polished sections gold is seen as irregular blebs in pyrite, chalcopyrite, and nagyagite, or as stringers in juxtaposition to one of these minerals; or these minerals may 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 metallic minerals, 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 of the sulfides are fractured, and 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 quartz is found to cut and replace pyrite especially, as well as 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 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 same activity. This type of wall-rock alteration typically accompanies what Lindgren (1900, p. 664–668) has termed "sericitic and calcitic gold-silver veins." These veins were later classed by Lindgren (1933, p. 544–555) as mesothermal.

Adjacent to the vein quartz, the quartz diorite wall rock has been bleached to a chalky-white to 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 fresh gray-colored 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 the 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 everywhere completely altered to patches of carbonate and fine-grained sericite, but in a few places several inches from the vein the feldspar twinning is 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 has 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 altered wall rock, but leucoxene is abundant locally, suggesting that the original magnetite may have been slightly titaniferous. In most places quartz in the altered wall rock is badly strained and commonly shattered, and where alteration has been intense the quartz is replaced by sericite.

At one place along the Independence vein, altered wall rock was sampled at points 1, 2, 5, and 8 inches respectively from the vein quartz to determine the mineralogic changes brought about as the intensity of alteration decreased.

Immediately adjacent to the vein quartz, the plagioclase of the quartz diorite is completely altered to sericite. Carbonate stringers are abundant. Some stringers show ragged walls indicative of replacement, whereas other veinlets show matching walls suggesting that minor movement occurred in the wall rock itself and allowed some open-space filling. Hexagonal outlines of some quartz crystals attest to open-space filling and perhaps slight silicification of the wall rock. Original quartz is sheared, strained, and largely replaced by sericite. Only a few isolated patches of this quartz now remain. The introduced quartz or quartz formed from silicate breakdown is clear and shows no strain effects. It is present either as small isolated crystals or as fine-grained aggregates in small veinlets. Masses of carbonate and muscovite laths probably represent original mafic minerals, none of which are preserved here. Even the chlorite formed from the breakdown of hornblende and biotite has in turn altered largely to muscovite. Secondary pyrite and arsenopyrite are common in this zone. Apatite of the original rock has been preserved throughout the entire width of altered rock between the vein and fresh quartz diorite.

In the zone 2 inches from the vein quartz, alteration is only slightly less intense. More of the original quartz is preserved, but it is highly fractured and traversed by sericite and carbonate veinlets. All plagioclase grains are completely altered to fine-grained sericite and carbonate. Some muscovite with wavy lamellae containing carbonate lenses is present. No mafic minerals are preserved, but they are now represented largely by patches of muscovite and carbonate. A black opaque mineral, ilmenite, is generally present sparingly. Arsenopyrite and pyrite also occur.

Five inches from the vein quartz the plagioclase is almost completely altered to sericite and carbonate. Quartz is not appreciably changed, but it is highly fractured and cut by carbonate veinlets which have replaced the quartz slightly along their walls. Some of the carbonate veinlets are clear, but some are a dull translucent brown. Many of the clear carbonate veinlets have a reddish-brown selvedge resembling limonite. Remnants of biotite are marked by patches of muscovite with minute carbonate lenses along the cleavage.

In the zone 8 inches from the vein quartz, the plagioclase is only slightly sericitized, and the rock looks only slightly bleached. Hornblende is recognizable but has been mostly changed to chlorite, as has the biotite. Carbonate is almost entirely lacking. Near chlorite grains are small patches of a black opaque mineral. Quartz grains show hairlike inclusions similar to those in normal unaltered quartz diorite. The quartz is typically fractured but otherwise has been little affected in this part of the alteration zone.

Within some parts of the veins small horses of quartz diorite have been partially preserved. This altered quartz diorite within the vein is known locally as "vein fill," and in some places it comprises most of the shear zone. For the most part the plagioclase is altered to carbonate and sericite just as in the altered wall rock. Quartz grains and any feldspar grains that 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 occasionally biotite plates with wavy extinction have been seen. As in the altered wall rock, patches of carbonate and muscovite probably mark the position of original mafic minerals. In general, alteration of the mafic minerals has gone completely through the chlorite stage and only muscovite and carbonate now remain. Opaque minerals are lacking 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.

Both in the wall rock and in the vein fill large quantities of carbon dioxide must have been brought in by the hydrothermal solutions that were circulating during vein formation and during metallic mineral deposition. These solutions carried sulfur and potassium also. The development of sericite attests to hydrothermal activity, although most of the constituents necessary for sericite formation were probably already present in the wall rock, except possibly for some of the water and potassium. Part or all of the calcium necessary for the development of calcite or ankerite could probably have been furnished by the plagioclase feldspar and perhaps to lesser extent by the hornblende, but carbon dioxide was brought in. Likewise sulfur for pyrite and arsenopyrite was brought in. The extreme development of sericite, accompanied by carbonates, suggests that the circulating solutions were alkaline.

The wall-rock alteration of the Willow Creek veins is markedly similar to that of the Grass Valley and Mother Lode veins in California. Chemical analyses of wall rock of the Grass Valley veins show generally an increase in potassium, sulfur, carbon dioxide, and subtraction of silica and soda. The same general relationships hold for wall rock adjacent to many of the Mother Lode veins despite the different wall-rock types. From microscopic study of wall-rock alteration in the Willow Creek district, it can be reasonably inferred that sulfur, carbon dioxide, and potassium were introduced, and that some silica was removed in the intensely altered areas where sericite has replaced quartz. In a few places, however, euhedral quartz is present in the wall rock, but it is not known whether this represents an addition of silica, or precipitation of quartz derived from silicate breakdown in the wall rock. Soda was probably removed where the plagioclase was strongly sericitized. In the similar gold quartz vein setting at Grass Valley, vein formation is pictured by Johnston (1940, p. 45–46, 60) as occurring in two stages, a stage of quartz deposition and a later stage of sericitization and introduction of carbonates. He believed that only the latter processes were strongly active in altering the wall rock. Likewise in the Willow Creek district sericitization and carbonatization were the dominant processes altering the wall rock. Although some secondary quartz may have formed, it is a minor product of the alteration.

Mineralogical changes in wall rock adjacent to productive parts of a vein are markedly similar to those adjacent to barren portions of the same vein. No diagnostic mineralogical criteria of wall-rock changes that may be useful as a guide to ore have been observed.

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 maps. 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 maps 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 quartz that has only a low gold content or is barren of gold. It must be remembered, of course, that mining has been carried beyond the limits of the richer shoots, and no stope map will give a representative picture of these shoots unless careful assays have been made. Unfortunately assay sheets either have not been kept for most of the small mines or are not available.

ORIGIN OF THE DEPOSITS

Development of shear zones.—In general, the shear zones containing the productive veins fall into two groups that are believed to be a direct manifestation of the internal tectonics of the quartz diorite in which they occur. A possible mode of develpment of these shear zones has been considered in more detail above (pp. 32, 34–35) under the discussion of fracture patterns.

Vein formation.—Deposition of vein material in certain California gold deposits from aqueous solutions, rather than from a dry siliceous melt, colloidal silica gel, or vapor phase has been discussed by various authors, and their conclusions summarized by Johnston (1940, p. 57–60). There is no reason to believe that aqueous solutions were not likewise responsible for the formation of the Willow Creek quartz veins. The hydrothermal alteration of the wall rock by solutions circulating in the vein channelways has already been discussed above.

Knopf (1929, p. 45) has suggested that the amount of silica removed from the wall rock along the Mother Lode gold quartz veins in California was much greater than that needed to form the quartz veins themselves. The wall rock would seem to be inadequate as a source of the vein quartz in the Willow Creek district, inasmuch as wall-rock alteration zones are almost always narrower than the adjacent quartz vein. Furthermore, the process of carbonatization, to which Knopf ascribes the releasing of silica from the wall rock, is a late process in the formation of the Willow Creek veins. Carbonate veinlets transect and fill cavities in the earlier quartz. In order for the wider veins to form, it would seem necessary that much silica had to be brought up from depth by hydrothermal solutions prior to carbonate filling and replacement, although the breakdown of silicates in the vein zone itself could have supplied considerable silica for vein formation.

From a study of polished sections and thin sections the conclusion is inescapable that open-space filling was a prominent process in vein formation. Comb quartz is abundant. That recurring movement took place within the veins is hardly to be doubted. Small shear planes are frequently observed in thin sections, and in hand specimens larger fractures, many of them subparallel to the vein walls, are conspicuous.

Structural control of ore bodies.—Although many of the ore bodies mined do not appear to have been influenced by any recognizable structural control, certain rich gold quartz shoots show a close association with certain structural elements, particularly with vein intersections. Stoll (1944, p. 211–214) has hypothesized, however, that vein areas of intermediate dip in the Independence mine were most productive. He visualized these areas as most susceptible to late fracturing in response to an assumed horizontal thrust. Late fracturing was considered by him to be a prerequisite to gold deposition. That post-quartz movement occurred in the planes of the veins has already been shown, but the writer doubts that the stress involved was a horizontal thrust perpendicular to the strike of the vein. If adjustment within the vein was in response to stresses which possibly formed the productive shear zones (see p. 35), then the direction of the late deforming stress could not have been horizontal (and in an easterly direction in the vein in question). Furthermore, if Stoll's general hypothesis is considered to hold for other veins in the area—those trending 060° to 080°—then a second, earlier or later, horizontal stress acting in a different direction must also be postulated. Even if late fracturing is granted as a prerequisite for gold deposition, could not this fracturing have taken place in response to a later stress acting in the same direction as that which is believed may have formed the original shears (i. e., shearing stress acting upward from northeast to southwest)? This application of stress would explain fracturing in both the north-trending veins and northeastward-trending veins.

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 to the northwest 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 rich ore was mined. It will be noted that the intersection of the "feeder" vein and main vein on the 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 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 in some places appear to be splits off the main veins; in most places, however, they are intersecting veins of the other productive shear zone, or veins parallel to 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 as the principal channelways for the gold-bearing 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 that were even more favorable for fracturing of the brittle quartz.

Mining in the Willow Creek district has not advanced far enough to more than suggest that certain geologic features are particularly important. This suggested importance is 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, but to the left when northeasterly-trending veins are viewed. An obvious exception is the occurrence of an ore shoot where two veins, parallel in strike but differing in dip, intersect.

MINES AND PROSPECTS

GOLD CORD MINE

The Gold Cord claims on Fishhook Creek were located in 1915 by Byron and Charles Bartholf. Development work appears to have been sporadic for many years, although a small production of gold was reported in 1917 and 1918. Older records indicate little real activity until 1931, however. Between 1931 and 1939, under the management of W. S. Horning and C. Bartholf, the mine was a steady producer, most of the ore coming from stopes above the 100 level. In 1939 the property was leased to a new group under the management of A. L. Renshaw. A new mill was constructed for the purpose of regrinding old tailings, and the last of these were remilled in 1939. From October 1939 to June 1940 some ore was mined from the 300 and 330 levels, and was processed in this mill. In June 1940 the regrind mill was rebuilt into the present mill. Mining operations which temporarily closed down in June 1940 were resumed in November of that year, and development work was carried out on the 360 and 400 levels from which some ore was later mined and milled. Development work was resumed after World War II, but there has been almost no gold production. Operations were discontinued early in 1949, and in October of that year the lower levels of the mine were allowed to flood.

The present Gold Cord mill is a well-constructed, well-arranged building. Ore from the mine goes to a Keuken-type jaw crusher which passes ½- to ¾-inch material. Belt feed carries the ore to a 3- by 6-foot (24-ton) Denver ball mill. Pulp from the ball mill then passes 6 silver-plated copper amalgamation plates 1 by 2 feet in size. Overflow enters a Dorr rake-type classifier which passes minus 65-mesh material to four Denver flotation cells where concentration is effected. Plus 65-mesh material is returned to the ball mill. Concentrates are shipped to the United States for processing.

The property of the Gold Cord Mining Company is now covered by 23 claims of which 9 are patented (pl. 4). The mine has been developed by several levels which extend over a vertical range of about 200 feet (pl. 5). Workings on the 100 level, including the old stopes from which much ore was taken, are now mostly inaccessible. On this level the vein strikes nearly due north and dips 45° W. Early mining was halted when the vein on the 100 level was cut off on the north by the Gold Cord fault—a major transverse fault 630 feet from the portal. Drag ore in the fault indicated that the block of ground north of the fault had moved relatively to the east. A vein segment approximately 125 feet east of the point at which the Gold Cord vein was cut off was followed north on the 100 level for more than 800 feet without encountering ore, although as much as 3 feet of quartz is present in some places along the shear zone. South of the major transverse fault the vein on this level was also cut off by a strike fault trending nearly due north and dipping 75° to the east. This is a reverse fault. A winze dipping 25° was sunk from the 100 level, but this failed to locate the vein at depth. In 1939 the 200 level was extended south from near the foot of this winze to the surface, following the vein for part of the distance. A winze dipping 42½° was then sunk on the vein and the 300 level opened up. Some ore was found which was taken out from the subsequently developed 330 level. Both "footwall" and "hanging wall" quartz bodies contained ore which was mined out in 1941.

A 260-foot drift south from the winze on the 300 level exposed a strong segment of the Gold Cord vein in places carrying 12 inches of quartz, but none of this was of a high enough grade to be mined profitably. Ground at the face of this drift is ravelly and suggests the proximity of a fault, probably the cross fault exposed above on the 200 level.

Development work was extended to the 400 level, but results were discouraging, although some ore was stoped above this level both on "hanging wall" and "footwall" bodies of quartz.

In order to locate the vein north of the Gold Cord fault, the 200 level was extended through the fault just before gold mining was closed down early in World War II. A crosscut was driven for 300 feet eastward in solid quartz diorite on the north side of the Gold Cord fault, but the vein was not encountered. A diamond-drill hole extending an additional 75 feet from the face of this crosscut also failed to locate the vein. A drift was then driven northward from the fault, and at a point 200 feet to the north a weak shear zone was penetrated. This was drifted on to the north for 1,200 feet more, becoming stronger in that direction, but quartz with significant gold content was found only at a point 340 feet north of the Gold Cord fault where a winze was sunk and a small amount of ore taken out. From this point a raise was driven which connected with the old workings on the 100 level above. Both on the north end of the 100 level and north end of the 200 level the vein is strong and carries as much as 3 feet of quartz in places, but the gold content is small. Additional drifting, and especially raising, would more adequately test the gold-bearing quartz in that part of the mine. South of the Gold Cord fault the vein is believed by mine operators to comprise a zone as much as 25 feet wide containing quartz along the footwall and hanging wall. Whether this is truly a vein zone with hanging wall and footwall quartz, or two distinct shear zones containing quartz, the presence of two minable gold quartz bodies south of the Gold Cord fault indicates that crosscutting or diamond drilling is desirable to test thoroughly the ground north of the major transverse fault. It is reported that 3 short diamond-drill holes eastward from locations north of the Gold Cord fault on the 200 level were in solid quartz diorite, but that 1 hole to the west may have cut through another shear zone. This can be adequately tested only by crosscutting.

In 1947 and 1948 two veins near the top of the mountain above the Gold Cord mine were explored by drifting, but no significant amount of gold was found. These drifts are at altitudes of 4,860 and 5,070 feet respectively (see pl. 1). The lower drift extends for about 295 feet along a weak, north-trending shear zone containing little or no quartz. The higher drift passed completely through the top of the mountain along a fairly strong north-trending shear zone that carried only little quartz and almost no gold. From the north portal a 2-inch air line was suspended by cable across a deep canyon to the next spur, about 1,300 feet distant to the north, and another vein several feet wide, which reportedly carried 2 ounces of gold per ton in surface showings, was drifted on for 50 feet at which point it pinched to a width of 5 inches. This was abandoned in October 1948.

During the winter of 1948–49 a raise was driven for 65 feet from a point 80 feet south of the Gold Cord fault on the 200 level of the main workings of the mine. This raise followed the steeply dipping strike fault which cut off the vein on the 100 level. A few pods of drag ore along this fault, averaging 5 ounces of gold per ton, were mined and milled. The raise finally holed through into stopes of the old workings on the 100 level.

Workings in the Gold Cord mine are probably the most complicated of any in the mining district. This is due to the relatively greater number and arrangement of post-ore faults. The most important of these is the Gold Cord fault, a major transverse fault striking 115° and dipping 80° to 85° SW. This fault is about 40 feet wide on the 100 and 400 levels but is 120 feet wide on the 200 level. The fault material is largely comminuted, strongly altered quartz diorite. A number of minor transverse faults also cut the vein. These are normal faults trending northwesterly and dipping steeply to the northeast; displacements are prevailingly less than 15 feet.

Strike faults are numerous throughout the mine. All of these faults strike nearly due north, subparallel to the vein, but dip to the east.

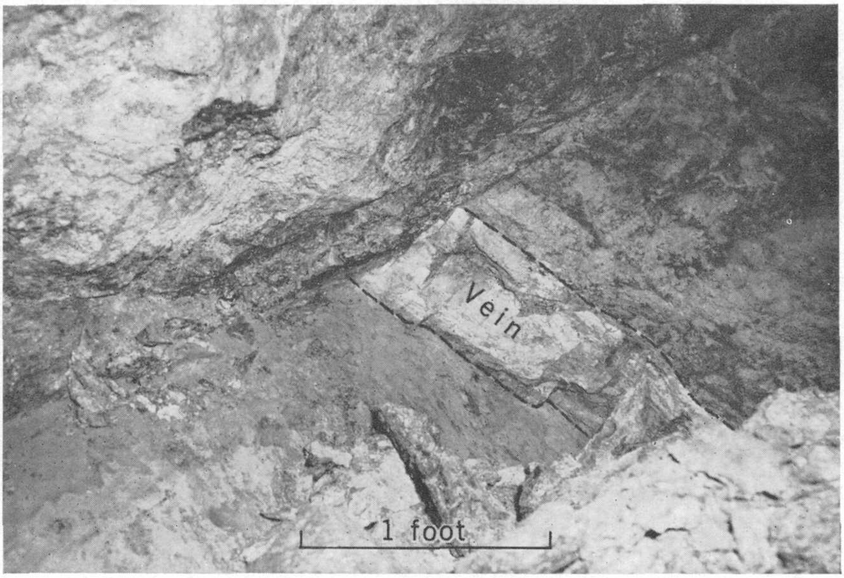

FIGURE 16.—"Footwall" vein cut off by strike fault on 300 level of Gold Cord mine.

Some of these are reverse faults, some normal. The widths of the faults are everywhere small, generally only a few inches. Workings on the 100 level bottom against a strike fault that has offset the vein more than 100 feet vertically. On the 200 level this fault shows only 1 to 6 inches of clay gouge, despite the large amount of vein displacement. Mining on the 300 and 330 levels was especially handicapped by two strike faults of normal displacement, one trending 157°, the second trending 160°. The dips average about 30° NE. The horizontal components of displacement of the vein were about 40 to 50 feet on these two faults where penetrated by the 330 level (pl. 5). Both these faults cut off the vein cleanly (fig. 16). On the 400 level the vein has been cut by yet another strike fault trending 172° and dipping 68° E. This is a clean-cut fault; the direction of displacement of the vein zone is not known. North of the Gold Cord fault on the 400 level is still another strike fault along which the connecting raise to the 350 level has been driven. This is a reverse fault of about 55 feet displacement in the plane of the fault. Generalizations relating to the strike faults must be used with caution, but it has been shown in development and mining at the Gold Cord mine that the low-dipping strike faults have a normal displacement, the steeply-dipping ones a reverse displacement.

The Gold Cord vein is considered by former mine operators to be a "vein zone" about 25 feet wide that includes minable hanging wall and footwall quartz separated by altered country rock. In a few parts of the mine where this relationship could be observed the writer has found unaltered quartz diorite separating the "hanging wall" and "footwall" veins. Whether these veins should be considered as part of the same "vein zone" therefore is doubtful. The cross section, plate 5, shows that the "hanging wall" and "footwall" bodies diverge with depth. Each body of quartz appears to be confined to a distinct shear zone, and in the following discussion the term "vein" may be taken to apply to either the "hanging wall" or "footwall" bodies as defined by the mine operators.

Quartz bodies in the Gold Cord mine lie in generally strong north-trending shear zones mostly from 3 to 4 feet wide. In places a zone may narrow to 6 inches; or it may widen to as much as 14 feet. In some places quartz completely fills the shear zone, but more commonly there is much comminuted, altered quartz diorite—or vein fill—associated with it. Inaccessible stopes from the 100 level are reliably reported to have exposed 14 feet of productive quartz, but this is certainly the exception as productive quartz is generally 2 or 3 feet wide at most and may be 1 foot or less. Older maps show the vein on the 100 level dipping 45° to the west, but in many places on lower levels in the main workings the dip is greater than 50°.

Along most of the drift on the 200 level north of the Gold Cord fault the vein lies in a shear zone as much as 6 feet wide. Dips are mostly between 35° and 45° W., somewhat less than dips south of the fault. Quartz ranges from a few inches to 3 feet in thickness and may be present as one band along the hanging wall, or in the center of the shear zone; it may consist of 2 or 3 bands each several inches wide; or it may consist of a multitude of minute stringers throughout the shear zone. In many places the quartz typically appears suddenly and then pinches out in a few feet.

Between the Gold Cord fault and the north end of the 200 level—a distance of approximately 1,400 feet—no major transverse faults were penetrated. In view of this fact, and the persistence of a strong shear zone containing as much as 3 feet of quartz in places, this block of ground would seem to be especially favorable for further exploration.

INDEPENDENCE MINE

The Independence mine camp, now part of the Alaska-Pacific Consolidated Mines, Inc., is located on Fishhook Creek about half a mile south of the Gold Cord mine (fig. 17). The first claims were staked in 1907 by the Alaska Gold Quartz Mining Co. Older records indicate little activity at the property until the late 1930's. At the time of the last Geological Survey investigation of the district (Ray, J. C., 1933) little real development work had been done, and only a small part of the present 700 and 900 levels had been opened up. Production records for the district indicate almost no activity at the mine until 1937 when W. W. Stoll, Sr., became general manager of the camp.

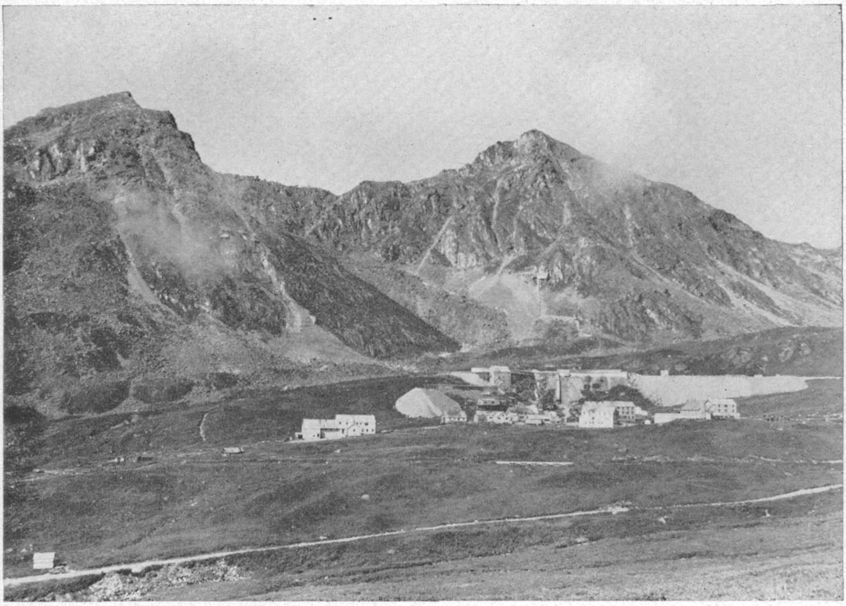

FIGURE 17.—View of Independence mine and camp.

Between 1937 and the closing of the mine under wartime regulations in 1943, the Independence mine was one of the more important producers in the district. Subsequent to the lifting of the wartime ban on gold mining in 1945 two unsuccessful attempts were made to renew operations. A third attempt to reopen the mine was undertaken in 1949. During the summer of that year rehabilitation work was carried out, and in September a small production began. The September operation marked the first time in the history of the Willow Creek district that contract mining was employed. Miners assigned to a certain block of ground in the mine received a minimum wage plus a portion of the returns on all gold mined by them. This incentive plan was apparently responsible for successful reopening of the mine. The plan was abandoned in 1950, however, and later in that year the mine closed down.

The surface plant at the Independence mine is the largest in the Willow Creek mining district. Ore is brought to the mill via a haulage tunnel at the mill level or via a double-track, gravity-operated, aerial tram from the 900 level. Oversize passing a 3/4-inch grizzly goes to a Keuken-type jaw crusher set at 1/4 inch. Belt feed moves crushed ore to two 3½- by 5-foot Marcy ball mills rated at 30 to 35 tons per day each. Pulp then passes over amalgamation plates where most of the gold is recovered. Overflow enters a Dorr rake-type classifier set to pass material of minus 85-mesh. Plus 85-mesh material is returned to the ball mills. Fines from the classifier next go to flotation cells where concentration is effected. Total recovery of mill heads is said to be about 97 percent. Of this 85 percent is recovered directly by amalgamation, the remaining 15 percent by concentration.

The Independence vein is almost unique among the productive veins of the district. It has a general strike of about 170° and dip of 20° W., but it exhibits rather marked changes in strike and dip in many places (pl. 6). Dips range between the extremes of 13° E., through horizontal, to 55° W. Changes in the direction of strike locally are rather sharp. The most pronounced changes in strike are in places where the dip is low, generally 20° or less. At these places it is to be expected that a slight warping of the shear zone or a slight irregularity in its surface when it formed would result in a notable divergence of the strike. These "rolls" or marked changes in strike of the vein have been considered by some to be significant in the localization of ore, but mining to date has shown no particular relationship between loci of ore shoots and axes of such "rolls."

The quartz of the vein ranges mostly from 1 to 6 feet in thickness, but this is by no means all productive. Many drifts and raises have exposed barren quartz or quartz with only a very low tenor in gold. The vein in places is composed of several narrow bands of quartz admixed with altered quartz diorite and clay gouge seams (fig. 18), although in many parts of the mine quartz appears as a single band

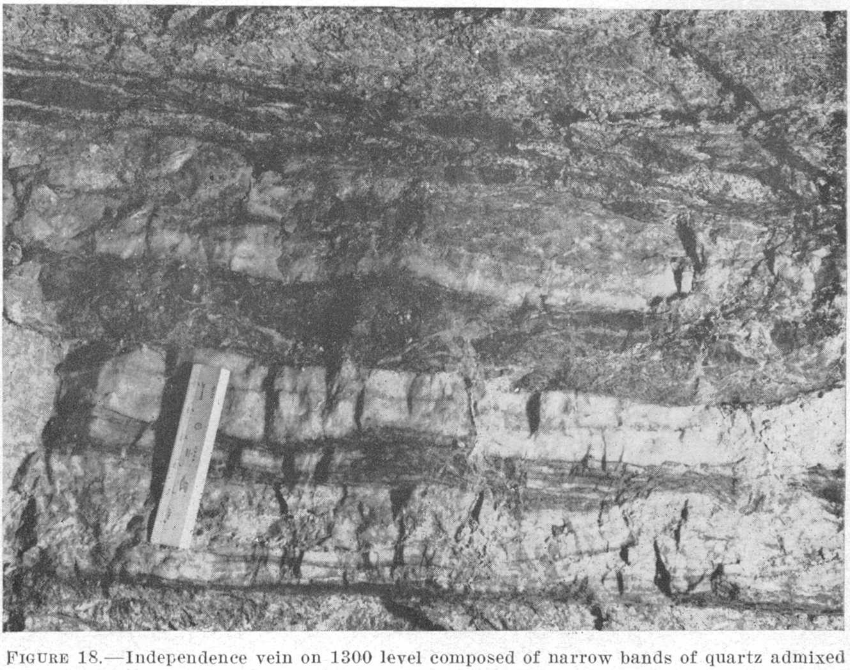

FIGURE 18.—Independence vein on 1300 level composed of narrow bands of quartz admixed with altered quartz diorite and clay gouge seams.

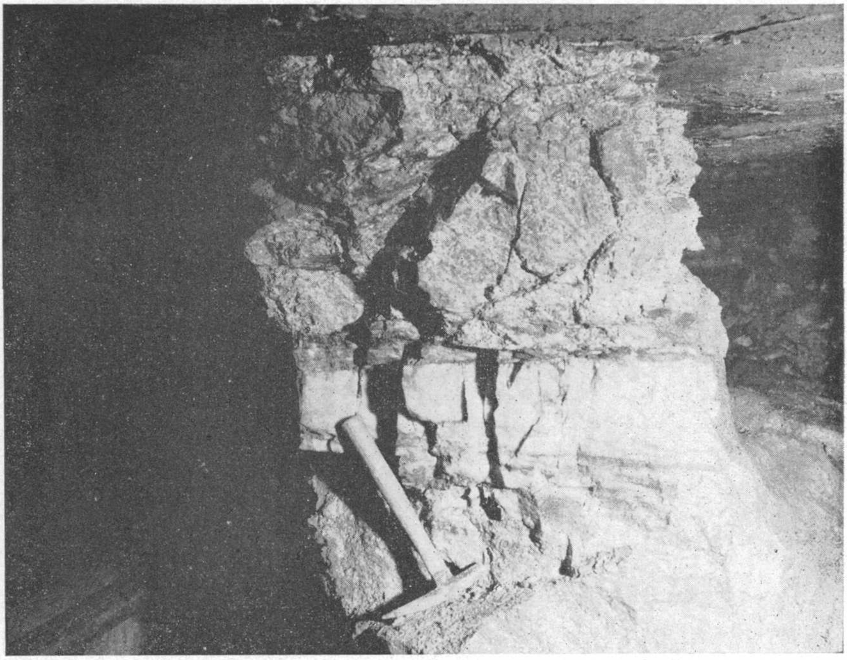

FIGURE 19.—Pillar in raise from 1300 level, Independence mine, showing quartz confined to central part of vein zone.

confined to the hanging wall, footwall, or central part of the vein zone (fig. 19). In places the vein is entirely filled with quartz which is strongly banded (fig. 20). Mining began at the surface and followed the vein downward. At present the vein has been explored to the 1500 level, which is more than 1,500 feet down the dip from the surface. Much of the ground between the surface and the 1100 level has produced good ore, although the blue banded quartz near the south end of the 1100 level is barren or of very low tenor in gold. Both immediately above and below the 1300 level large tonnages of ore have been stoped out, and on the 1370 and 1400 levels a unique structural condition resulted in a rich ore shoot from which a considerable amount of high-grade ore was mined.

On the 1370 and 1400 levels, the Independence vein reverses dip and forms a small synclinal structure which is closed on the south end (pl. 6). The trough of this structure is intersected by a footwall vein which has been explored on the 1500 level (fig. 21). Quartz on the 1370 and 1400 levels ranged from a few inches in width along the hanging wall to as much as 6 feet of banded quartz that completely filled the shear zone. When this part of the mine was worked the intersecting footwall vein was followed downward in the erroneous belief that it was the main vein, but the tenor of ore rapidly decreased. Subsequent exploratory work exposed the main Independence vein

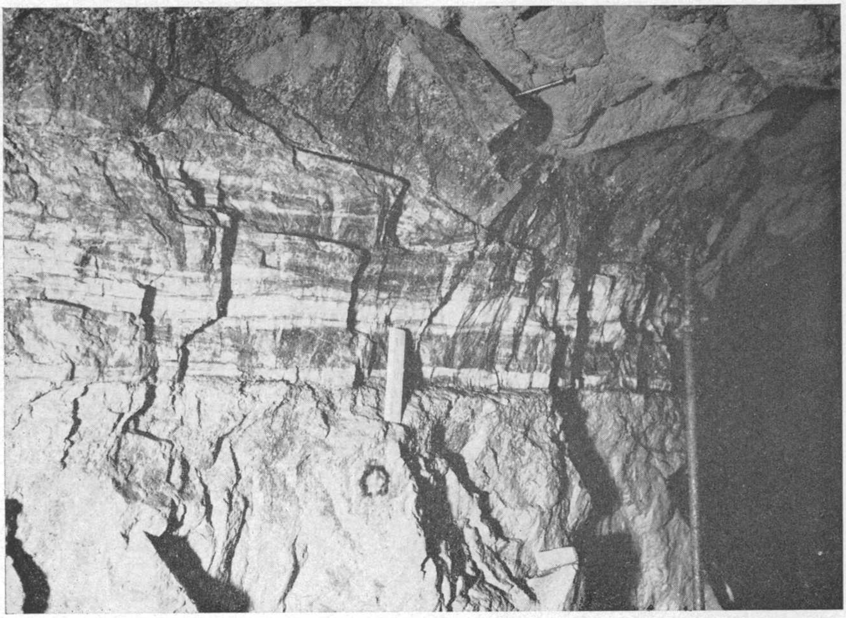

FIGURE 20.—Strong banding in Independence vein, 1100 level. Dark bands are blue quartz.

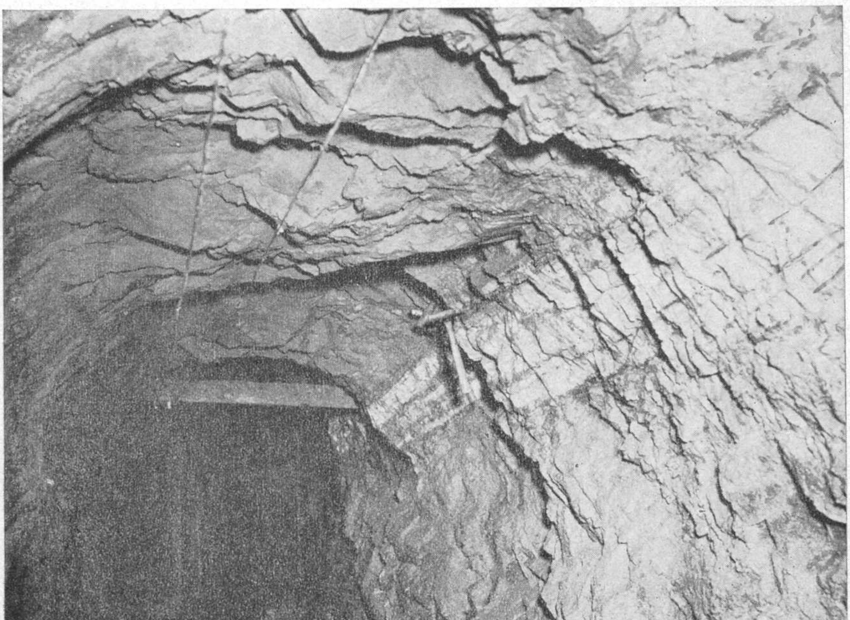

FIGURE 21.—Intersecting vein on 1500 level, Independence mine.

very poorly defined to the west on the 1370 level and to the north on the 1500 level (pl. 6).

At the south end of the main workings the Independence vein has been cut off by the Martin fault—a major transverse fault trending 130° and dipping about 54° NE. The fault zone is reported to be about 140 feet wide where it has been penetrated on the 900-level southwest crosscut. Drag on the hanging wall of the fault exposed on the 1300 level indicates a normal fault with the northeast side dropping down. To date (1950) the extension of the Independence vein south of this fault has not been found. Inasmuch as no veins were cut in the southwest crosscut which penetrated the Martin fault and extended for approximately 1,000 feet through the mountain, it seems likely that the throw on this fault may be such as to place the southern extension of the Independence vein above the present erosion surface east of upper Willow Creek. If the faulted segment of the vein had a strike and dip similar to the average strike and dip north of the Martin fault, it would seem likely that the vein should appear again north of the Gold Dust fault in the valley of upper Willow Creek or on the slope northwest of the stream (pl. 1). The presence of a gold quartz vein on the slope northwest of the stream has been mentioned above (p. 31).

Many minor faults are known to cut the vein mostly in a transverse direction, but these could not be seen for the most part owing to heavy timbering along the shear zone and to the inaccessibility of all workings between the surface and the 900 level, and most of the workings on the 960, 1200, and 1250 levels. Many of these faults shown on plate 6 were taken from maps by Stoll (1944). Where minor faults can be observed they do not drag the vein but cut it off cleanly (fig. 22). Segments of two strong strike faults have been seen in some parts of the mine. One is exposed on the 1100 level near the head of the winze to the 1200 level. At that point the fault trends about 165° and dips 70° E. The walls are somewhat irregular and enclose 2 to 3 feet of slabby, slickensided rock. Vertical displacement of the vein here is only 2 feet, but slickensides plunging gently to the south indicate that the footwall has moved about 17 feet to the south. Like the steeply dipping strike faults in the Gold Cord mine this is a reverse fault. Broken ground at the main raise station on the 1300 level may be a downward extension of this fault (see pl. 6). A second strike fault is exposed on the 1250 level and in the stopes to the south from this level as well as in the crosscuts just south of the transfer bin on the 1300 level. The strike ranges from 155° to 170° and the dip from 50° to 63° E. The direction of displacement and the amount of offset cannot be determined in the few accessible workings where the fault has been observed.

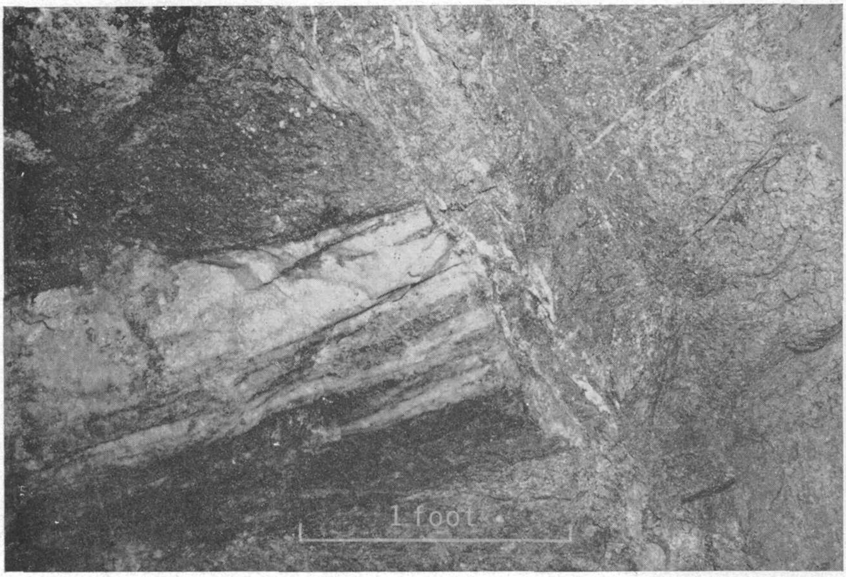

FIGURE 22.—Independence vein cut off cleanly on 1100 level by minor strike fault. Fault is normal, dropping vein about 2 feet.

The mine is ideally set up for continued work on the Independence vein. During full scale operations prior to World War II a haulage, drainage, and exploratory tunnel was driven for several hundred feet at the mill level, also called the 2000 level. The portal of the 2000 level is at an altitude of 3,580 feet. This level extends underneath the 1500 level, the lowest point in the mine where the main vein has been explored. The 1500 level and the haulage or mill level are about 250 feet apart vertically. A second subparallel vein known as the Skyscraper vein occurs a few hundred feet above the Independence vein. Surface cuts expose 18 to 20 inches of quartz in places on the Skyscraper vein, but little real development work has been done. At one point on the 900-level southwest crosscut a long raise was driven to intersect the Skyscraper vein underground, but active development in this part of the mine has not been pursued.

A strong vein about 3 feet wide striking 165° and dipping about 40° W. was penetrated 460 feet from the portal of the 2000 level. This is believed by some to be a southern extension of the vein worked at the Gold Cord mine half a mile to the north, although drifting to the north and south gave discouraging results. In order to determine the possible relationship between these two vein segments a transit survey was carried out between the Independence and Gold Cord mines. A strike of nearly due north and a dip of 45° W. were assumed and the Gold Cord vein was projected to the 2000 level of the Independence mine. The survey indicates that the two vein segments in question cannot be related unless transverse fault movement between the two mines was at least 300 feet.

During 1950 some ore was being mined from the south end of the 1100 level where a shallow winze to the south was sunk on the vein. A development heading was continued to the west from the 1500 level.

FERN MINE

The Fern mine on Archangel Creek is on ground originally known as the Fern-Goodell property. So far as is known the property was located about 1917 on the Hillis group of claims. Active development work was undertaken soon after, and production began in 1922. In 1925 the adjoining Talkeetna mine property was taken over by the Fern Gold Mining Co., but actual gold production continued only from the Fern mine. Production records show that no gold ore was milled in 1929 or 1930, but in 1931 T. S. McDougal continued active development work and a substantial amount of gold was recovered that year. Between 1931 and 1941 the mine was operated almost continuously by T. S. McDougal, and it is estimated that during this period somewhat more than $1,000,000 worth of gold was mined, principally from the No. 2 and No. 3 levels; there was also some production of gold from the No. 4 level. The lease was maintained by McDougal until 1945 when a group managed by A. G. Dodson acquired it. Development work was resumed in that year, but in 1946 the Fern mill was destroyed by fire, and development work was consequently slowed down. The following season was spent largely in rebuilding the mill, although a small amount of underground development work was done. During 1948 the present mill was completed, and some ore was mined and milled from the No. 1 hanging-wall vein on the No. 4 level (pl. 7). This was the first mining and milling operation in the Willow Creek district after the termination of World War II. The winter of 1948–49 was spent driving under the old No. 3 level by drifting and raising from the No. 4 level. The old drift along the Fern vein on the No. 4 level was abandoned because of cave-ins. In circumventing this drift the No. 1 hanging wall vein with low gold values was encountered and drifted on for about 160 feet. From a point on the Fern vein just southwest of its intersection with this hanging-wall vein a raise was driven on the Fern vein for 150 feet. In December 1948 this penetrated a sub-level below the old No. 3 level, but impounded water and muck forced the operators to abandon the raise. From a point a few feet to the southwest on the No. 4 level a vertical raise was then driven for 210 feet to a point about 50 feet in elevation below the old No. 3 level, and about 125 feet to the north. A crosscut from the top of this raise encountered a second hanging-wall vein containing encouraging showings in gold. Stoping was begun upward on the vein and by July 1950 was in permanently frozen ground near the surface. The ore was reported to have averaged about $75 to the ton in gold. Operations were suspended in July 1950 in preparation for driving a crosscut from the No. 4 level to intersect the downward extension of the No. 2 hanging-wall vein, but in September the mine manager died and development plans were temporarily laid aside.

The Fern mill circuit is similar to that at other properties in the district. Ore is electrically trammed to the mill where it is reduced in a jaw-type crusher before passing to a ball mill of about 25-ton capacity. Most of the gold is recovered directly on amalgamation plates, overflow going to a Dorr rake-type classifier and thence to flotation cells for concentration.

The main Fern vein, which has not been worked for some time, is a notably wide shear zone consisting in large part of altered comminuted quartz diorite plus a considerable amount of clay gouge in places. Minable quartz occurs as long contorted lenses, aggregates of small lenses, or branching quartz stringers a few inches wide. In the old No. 3 level, now inaccessible, the shear zone attained a width of 17 feet at the foot of the first winze from the No. 2 level (fig. 5). The zone trends 060° on the average and dips 43° to 52° NW. In the older workings on the No. 2 level the vein was cut off on the southwest by a strong post-ore fault trending 130° and dipping 54° NE. In abandoned workings south of this fault a similar vein zone, believed to be the western extension of the Fern vein, was encountered somewhat more than 300 feet to the northwest. The long drift south of the fault is along a narrow vein which is definitely not the Fern vein. On the present No. 4 level the Fern vein is also cut off on the east by a second major post-ore fault nearly 100 feet wide trending 140° and dipping 72° SW. The eastward continuation of the vein has been located about 250 feet to the northwest. It thus appears that the vein segment between the two major faults is in a graben, or downfaulted block (see pl. 1). The actual direction of displacement is not observable, but it seems likely that the greater component of movement on these faults was in a vertical direction. Downfaulting of the block in which the productive part of the mine is located would explain the apparent horizontal displacement of the Fern vein.

The locus of ore shoots at vein intersections is well demonstrated in the Fern mine. Recent mining has been confined to the No. 2 hanging-wall vein just north of its intersection with the Fern vein. This hanging-wall vein trends nearly due north and dips 45° to the west, thus conforming in general to the north-trending productive veins of the district. The No. 2 hanging-wall vein in places is only 12 to 15 inches wide and is entirely filled with minable quartz (fig. 23). It pinches and swells along the strike and locally forms a vein zone as much as 4 feet wide composed of branching quartz stringers in altered quartz diorite (fig. 7). Richer parts of the Fern vein mined in the past on the No. 3 level were also at the intersection of this hanging-wall vein with the Fern vein. The discovery and indentification of tellurides reported herein was from ore samples along the No. 2 hanging-wall vein.

Although the intersection of two veins may be expected to produce minable quartz bodies, there is no certainty that these will be shoots of high tenor in gold or always of minable widths. The No. 1 hanging-wall vein in the Fern mine has been explored rather thoroughly on the No. 4 level, but only a small amount of ore was mined from it. Yet it has a strike and dip similar to that of the No. 2 hanging-wall vein which has yielded high tenor gold ore. The No. 1 hanging-wall vein ranges from a few inches to 18 inches in width and may be barren of quartz, or may contain as much as 16 inches of quartz. The occurrence of quartz as small lenses separated by altered quartz diorite and clay gouge is typical (fig. 24).

The intersections of footwall veins with the main veins is held by some to produce richer shoots than intersections with hanging-wall veins. In any event where the No. 1 and No. 2 hanging-wall veins in the Fern mine pass into the footwall, minable quartz bodies can probably be expected, and these may be loci of high tenor ore. These potentialities, plus the presence of known ore in the No. 2 hanging-wall vein that has not yet been exploited from the No. 4 level, make the outlook for the Fern mine promising.

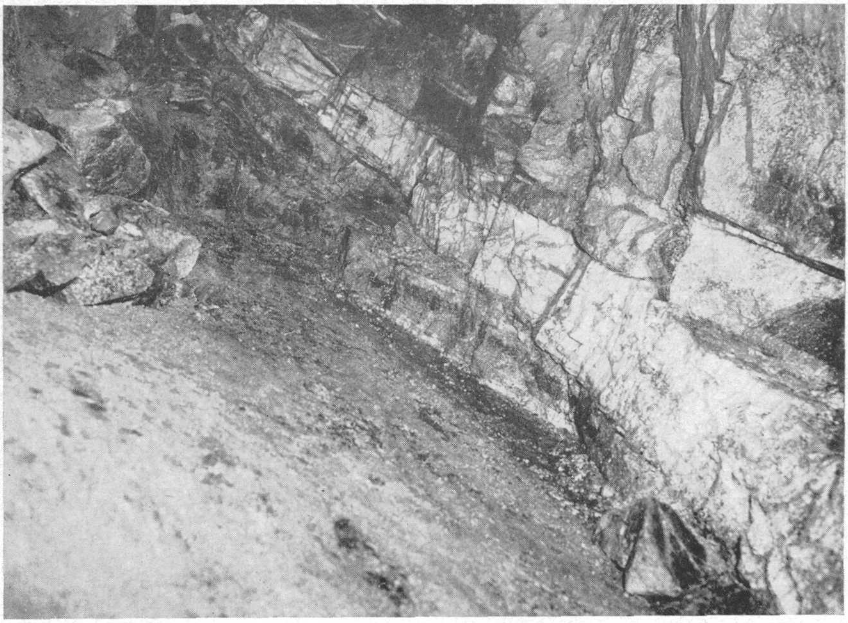

FIGURE 23.—No. 2 hanging-wall vein, Fern mine. About 14 inches of quartz fills zone here.

FIGURE 24.—No. 1 hanging-wall vein, Fern mine, showing small lenses of quartz separated by altered quartz diorite and clay gouge.

Along the first few hundred feet of the No. 4 level several small quartz stringers, mostly quartz-filled joints, were exposed. At a point 1,100 feet from the portal, however, a vein trending about 050° and dipping 74° NW. was cut. This vein is about 2 feet wide and consists mostly of sheared quartz diorite and gouge. As much as 8 inches of quartz is present along the center of the zone, but this did not contain encouraging gold values. Concentrates from this zone show small amounts of scheelite.

MABEL MINE

The Mabel mine is located at an altitude of 3,850 feet near the top of the divide west of the junction of Reed and Archangel Creeks. The mine is approximately 1,600 feet above the mill and lower camp, and is 1,800 feet above the valley floor of Archangel Creek. A double-track, gravity-operated, aerial tram about 3,250 feet long connects the lower camp with the mine.

The Mabel mine is among the oldest mines in the Willow Creek district; the first claims were staked in 1911. Mining and development work were carried on only intermittently until 1917, but between 1917 and 1930 the Mabel mine contributed almost continuously to the annual production of gold from the Willow Creek district. Production records for the district indicate no active mining at the Mabel mine between 1931 and 1937, but there was a small production of gold in 1937, 1938, and 1939. During the war years, the mine was inactive, but some development work was carried out in 1946 and 1947. Since 1947 the property has been closed down.

The Mabel vein strikes nearly due north and dips between extremes of 23° and 66° W. More commonly the dip is between 35° and 45°. Most of the active mining has been confined to a vein segment lying south of a major transverse fault—here called the Mabel fault—which extends through the mine (pl. 8). This fault strikes 125° and dips 74° NE. It has displaced the vein approximately 150 feet, the block north of the fault moving relatively to the southeast and downward. A second smaller but parallel fault, well exposed in the long raise from the 600 level north of the Mabel fault, has displaced the vein an additional 100 feet in the same direction.

Aside from the 300 level at the same elevation as the mine buildings, most of the exploitation of the vein has been downward. This has burdened the operators with the problem of pumping the lower levels, although there is a considerable amount of seepage through the fractured country rock and during dry periods the lowest mine level is partly accessible without pumping. Plate 8 shows that the vein was mined up to the major transverse fault which cut off the ore body. North of the fault the vein extension has been relatively unproductive. A long raise on the vein from the 600 level north of this fault failed to encounter minable quartz. If the greater component of movement on the post-ore faults is in a vertical direction, then the northward extension of the ore shoot may lie below the present workings.

The Mabel vein zone ranges from a few inches to as much as 10 feet in width. In the wider zones as much as 3 feet of quartz is commonly present. Quartz may appear as a band several inches wide in the center of the shear zone, or it may occur along the footwall or hanging wall; in some places narrow stringers of quartz break across from footwall to hanging wall. In a few places the vein zone is completely filled with quartz. Quartz is mostly coarsely crystalline and massive, but open vugs were seen in some specimens. On the north end of the 300 level banded quartz is present locally. As in other veins in the mining district pinching and swelling along the strike and down dip is characteristic. On the 300 level south of the Mabel fault the vein splits along the strike. The 200 level, now mostly inaccessible, was partly along this footwall split. There has been some post-mineral movement in the plane of the vein but this was small. An aplite dike in the winze just above the 400 level rolls up into the footwall of the vein which suggests a reverse movement in the plane of the vein. The reverse movement is well demonstrated in the raise at the south end of the 500 level where an aplite dike has been offset about 10 feet. Slickensides along the hanging wall of the vein on the 400 level show that the hanging wall block moved upward and to the south. The Mabel vein is not everywhere well defined and in some areas passes into generally broken ground and loses its identity as a vein altogether. Several feet of such broken ground must be passed before the vein exhibits well-defined walls again. This was particularly noticeable on the 400 and 500 levels just north of the main winze.

Because of the location of the Mabel mine, and because the mine policy has been to sink on the vein, continued development work will be expensive. Unless a very good grade of ore is discovered mining will not be economically feasible under present conditions. Ideally the vein should be tapped at a lower level, but inasmuch as the vein dips away from the mill and tram side of the mountain, this would involve a considerable expenditure for driving the long crosscut that would be necessitated at the lower level. However, it is difficult to see how any substantial production can be attained until such lower workings are established.

LONESOME MINE

The Lonesome mine, formerly part of the Gold Mint mining property, is situated on the southeast side of the Little Susitna River about 3 miles above the mouth of Archangel Creek. At present there is a small bunkhouse and mill on the property. Both buildings were constructed in 1948 and are in excellent condition. An abandoned stamp mill was demolished by a snowslide in the spring of 1949, and an older log bunkhouse burned in 1950.

It is not known when the first claims covering the Lonesome mine were staked, but the property was worked intermittently from 1931 to 1938 when a 5-year lease with an option to buy was given to Fred Johnson. The ground was abandoned in 1940, the owners died, and the property reverted to public domain. In 1946 the property was restaked by Lloyd Hill and Charles Cope, 9 claims being recorded at Wasilla. Since 1946 work has consisted mainly of installing the mill and opening up the vein, although some ore was milled in 1948 and 1949. No active work was undertaken in 1950.

A Denver ball mill rated at 18 to 24 tons per day has been installed in the mill building. This ball mill has a classifier head screened to pass minus 40-mesh material. Primary recovery of the gold is by amalgamation. All material passing the amalgamation plates goes directly to 4 flotation cells where part of the remaining gold and metallic sulfides are concentrated.

The vein at the Lonesome mine is virtually unique in the Willow Creek district in that it has, in places, a high silver content associated with the gold. The strike of the vein ranges generally from 140° to 150° and the dip from 43° to 62° SW. Nowhere does the vein exceed 18 inches in thickness, and consequently much waste must be taken out. In general, the strike and dip of the vein are subject to considerable variation. Pinching and swelling are characteristic, and rolls associated with pinching down dip are not uncommon. A fine-grained, highly fractured gabbro forms the country rock.

To date (1950) the vein has been explored by 3 adits at different altitudes (fig. 25). The highest, or No. 3 adit, has exposed the vein for only 110 feet. Some ore was stoped from this level; a small amount of high-grade ore remains. On the No. 2 level the vein was followed for 120 feet to a point at which it was cut off by a strong cross fault about 2 feet wide. Displacement of the vein was several feet to the southwest, but crosscutting in this direction by former operators was not carried far enough and hence the faulted segment was not found on this level. Crosscutting was then carried out to the northeast in the mistaken belief that the faulted vein segment had been thrown in that direction. Along the No. 1 level, which extends for about 400 feet, the vein is very irregular. It pinches, swells, and rolls in several places and near the end of the drift splits along the strike. Minor faulting is very common, but the vein can be followed without much difficulty. At a point 300 feet from the portal good ore was encountered and in 1948–49 a raise was driven for about 50 feet on the vein. The gold content of the ore decreased rapidly and became low in the raise, however. An air raise, from this raise on the vein, designed to break into the No. 2 level, is now 10 feet above that level and 30 feet southwest of it.

At the downward extension, on the No. 1 level, of the strong cross fault exposed on the No. 2 level, the vein is only 2 to 3 inches wide, but it assayed 19 ounces of gold and 22 ounces of silver to the ton. Early in 1949 a short test raise was driven in this area, but results were discouraging. Operations closed down in July of that year.

Sinking from the No. 1 level has been suggested as a means of opening up a likely area for additional ore, but such a program, necessarily an expensive one, would involve a water problem resulting from the highly fractured nature of the country rock, and offers no guarantee of finding ore.

Surface trenching to the east of the mine has exposed vein material for several hundred feet. If this material represents the same vein that is exposed underground, as seems likely, then future mining operations should be assured of several hundred feet of backs as the vein is explored farther to the southeast.

In a saddle of the spur 0.6 mile east of the mine trenching has exposed oxidized vein material of high silver content, as much as 400 ounces to the ton, in the gabbro country rock. Southeast of this saddle similar vein material has been exposed well within the boundary of the basal conglomerate, considered Eocene in age by earlier workers, which lies unconformably on the batholith. It is not known

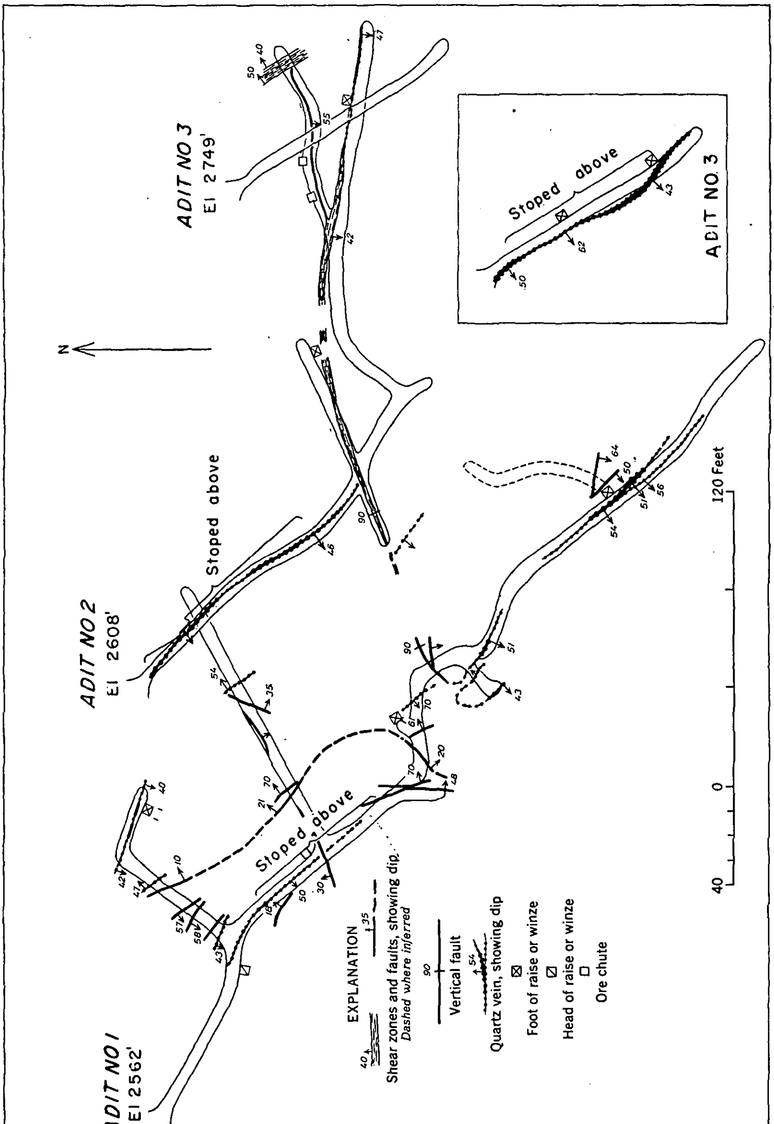

FIGURE 25.—Map showing workings of Lonesome mine.

whether this vein belongs to the same metallogenetic epoch as other productive veins in the Willow Creek district. However, so far as can be determined from the trend and apparent dip of this vein, it may well be an upward projection of the Lonesome vein, which carries the tellurides nagyagite and altaite as do the Fern and Schroff-O'Neil veins. If this correlation is correct then a post-conglomerate (and post-Eocene?) age of the Willow Creek gold deposits would be indicated. This would not mean that the shear zones in which the gold deposits occur were not related to the tectonics of batholith intrusion, or that the introduction of gold bearing quartz—a late phase of batholith activity—might not have persisted into early Tertiary time.

SNOWBIRD MINE

The Snowbird mine is located at 4,350 feet altitude on the south side of a hanging valley that is tributary to the head of Reed Creek valley from the west. Prospecting was first carried on in 1921, but little further work was done until 1939. Between 1939 and 1941 several short tunnels were driven, mostly into the talus above the present mine portal, and some coarse quartz containing free gold was discovered. It is believed by some that the gold-bearing quartz is largely float, although quartz is exposed in one of the tunnels now accessible. In 1945 a road and lower camp were constructed in Reed Creek valley, and a 5,000-foot, heavy-duty, double-track, reversible, power-driven aerial tram to a camp site in the hanging valley 1,250 feet above was begun. The tram and upper camp were completed in 1946, and a long crosscut to intersect the downward extension of two veins known from surface cuts was begun. The mine portal is connected to the mill building at the upper camp by a new 1,600-foot, double-track, gravity-operated aerial tram.

Milling installations were completed in 1950. Ore goes to a primary jaw crusher and then to a ball mill rated at 30 to 40 tons per day. A jig in the circuit is designed to remove coarse gold before pulp passes over the amalgamation plates. A spiral-type classifier returns coarse material to the ball mill and passes fines to four flotation cells where concentration is effected. Electric power is furnished by a diesel power plant at the lower camp. The power plant was designed to operate by water power during the summer months.

Four shear zones are explored underground by about 2,000 feet of crosscuts and drifts (fig. 26). The first shear zone was cut about 540 feet from the new portal. This zone trends 053° and dips 54° NW. Where it is penetrated by the crosscut it is about 7 feet wide and consists mostly of sheared quartz diorite with only one or two quartz stringers an inch wide. A second barren shear zone striking 080° and dipping 67° NW. was cut about 635 feet from the portal. About 800 feet from the portal a strong shear zone 10 to 12 feet wide—the Snow-

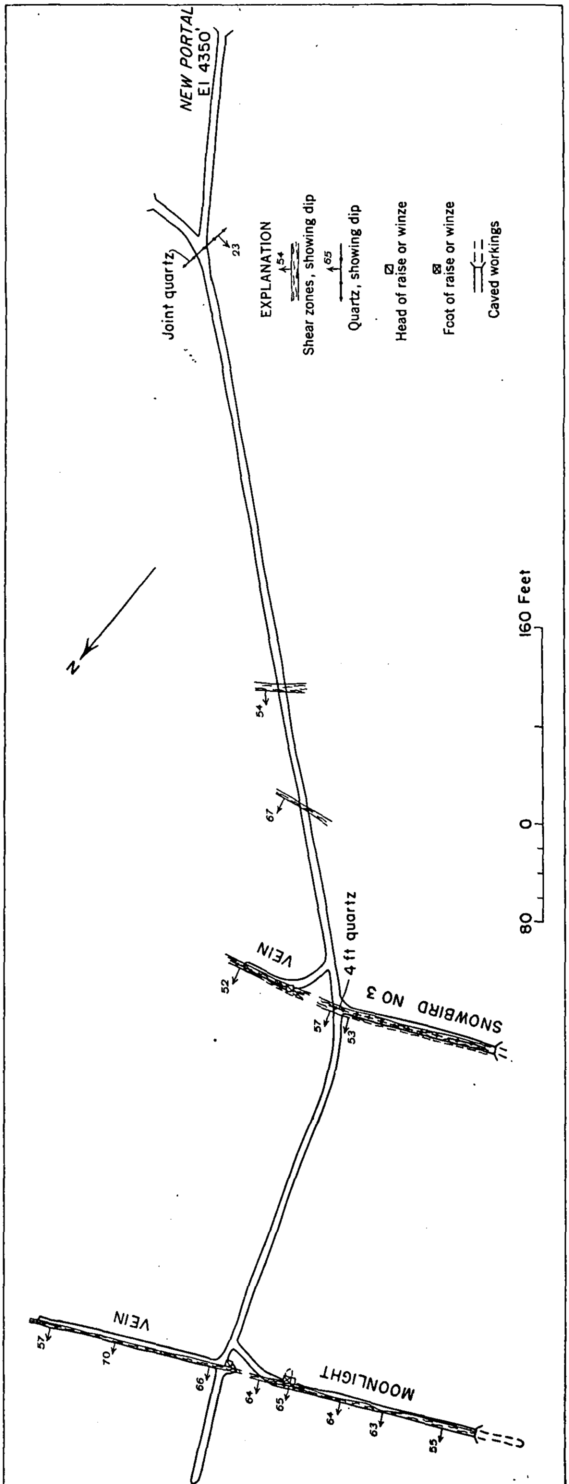

FIGURE 26.—Map showing workings of Snowbird mine.

bird No. 3 vein—containing lenses of sugary quartz aggregating 2 to 3 feet in width was crossed in 1947. The quartz lies in a matrix of comminuted quartz diorite and clay gouge (fig. 6). The vein strikes about 070° and dips 52° to 57° NW. Exploratory drifting was conducted in 1948 for about 175 feet on this vein which is in all respects similar to the Fern vein and may represent an eastward continuation of it (see figs. 5 and 6). High gold assays have been made on quartz immediately adjacent to the hanging wall where it was penetrated by the main crosscut, but over most of the width of the vein the quartz is nearly barren of gold. In 1950 a winze was sunk on the Snowbird No. 3 vein, but the reported gold values proved to be of localized occurrence.

Approximately 300 feet north of the Snowbird No. 3 vein a fourth similar vein zone, known as the Moonlight vein, was cut in 1948. In the crosscut this is a narrow zone about 18 inches wide containing a few contorted lenses of quartz in a matrix of sheared quartz diorite and clay gouge, but in the drift to the northeast and southwest the zone widens to as much as 6 feet in places. The vein strikes 065° and dips 55° to 70° NW. A small stringer of quartz in the northeast drift along the hanging wall is reported to have yielded a high gold assay. In the southwest drift 30 inches of quartz with encouraging gold values was cut, and during the summer of 1950 a raise was put up on the Moonlight vein in this drift. The raise was designed to prospect the quartz zone that was cut in this drift and to drive towards the intersection of the Moonlight vein with a vein zone suspected from surface prospecting, but bad ground forced abandonment of the raise. Drifting to the northeast was abandoned in September 1950, and the property was closed down for the winter. A small amount of ore was milled in September.

SCHROFF-O'NEIL MINE

During the summer of 1950 a small vein segment perched at 4,900 feet altitude on the Craigie Creek side of the pass from upper Fishhook Creek was worked from surface exposures by Ward Schroff and Frank O'Neil. The vein trends generally 070° and dips from 21° to 34° NW. Only a small segment of the vein now remains and this is entirely exposed to erosion. Its extension to the south, west, and east is above the present erosion surface, and to the north the vein is cut off by a strong fault which appears to be of normal displacement, the north side dropping down (see pl. 1). The northward continuation of the vein has not been located.

A barren copper-stained quartz vein trending about 030° and dipping 33° NW. intersects the Schroff-O'Neil vein, and it appears that this intersection may have been significant in localizing the gold-bearing quartz. The quartz is 1 to 6 inches thick, mostly coarsely crystalline, much of it vuggy. Coarse gold is abundant both free in the quartz and associated with galena. Galena is not generally conspicuous in the Willow Creek ores, but at this locality large cubes are common. Also associated with the galena and gold are pyrite, sphalerite, chalcopyrite, and tetrahedrite, as well as the tellurides nagyagite, altaite, and coloradoite (?).

HIGH GRADE MINE

The High Grade mine is located at an altitude of 4,100 feet near the head of Fishhook Creek valley. Only assessment work and a little development work has been done since 1930 when a small amount of ore was shipped to the Tacoma smelter. The main workings, all on one level, consist of nearly 1,000 feet of drifts and crosscuts (fig. 27). About 65 feet from the portal a shear zone trending 170° and dipping 28° to 38° SW. was cut. To the north the strike of the shear zone swings to about 160°. Only a small amount of quartz is visible, but this reportedly included local high-grade pockets of gold quartz. Numerous slickensides indicate a steep reverse movement which caused the hanging wall of the shear zone to move upward and to the south. Two other shear zones were exposed underground, one trending 165° and dipping 40° SW., the second trending 167° and dipping 35° to 45° SW. No minable quartz was found in any of the 3 zones cut underground.

One-quarter of a mile to the north several small veins parallel to the strong southwest-dipping joint set have been prospected by surface workings and by short drifts underground. None have proved to be of economic value.

MARION TWIN MINE

The discovery date of the Marion Twin vein is not known, but records for the district show that production from this property began in 1928 and continued through 1931. There was some production in 1935, and the last work reported done at the Marion Twin mine was in 1937. The property is situated at 4,500 feet altitude near the head of Craigie Creek just below the Schroff-O'Neil mine. The gold recovered came from an open cut near the surface not more than 50 feet long and 20 feet wide on a nearly flat vein segment dipping gently to the northwest. At the east end of the cut part of the vein can still be seen. Here it is only 1½ inches wide and consists of coarsely crystalline quartz containing pyrite, galena, and free gold. To the south the vein rolls gently upward and offsets a 6-inch copper-stained joint-quartz vein 2½ feet. The displacement is normal. Where the vein rolls, it becomes a barren shear zone and prospecting beyond this point has been to no avail.

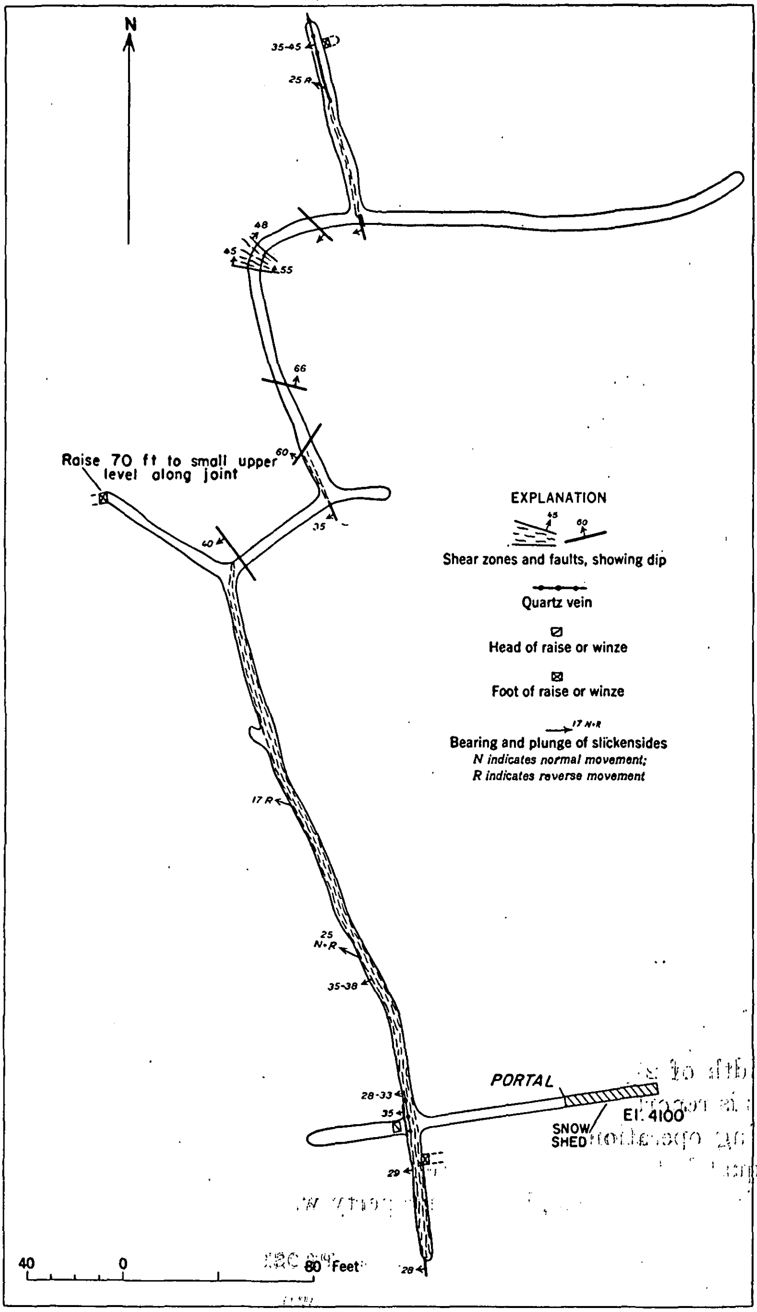

FIGURE 27.—Map showing workings of High Grade mine.

THORPE MINE

Only one productive gold quartz vein in the mica schist country rock of the Willow Creek district has been exploited. This is at the Thorpe mine on the west fork of Grubstake Gulch, nearly 2 miles south of the schist-quartz diorite contact. The property was located sometime prior to 1930. Several adits have been driven to explore the ground and work the vein, but only one crosscut, located at an altitude of 3,075 feet, was accessible in 1950 (fig. 28). At a point 425 feet from the portal this crosscut intersects the main vein trending 120° and dipping 60° NE., but on this level the vein consists only of a wide shear zone of comminuted schist. A long raise on the vein from this level is reported to have penetrated as much as 3 feet of gold quartz ore which was mined out in 1942–43. The Thorpe vein is not parallel to the foliation and bedding in the schist but intersects it at an angle of approximately 60°. Nor does the vein conform to the pattern established by the productive veins in the quartz diorite.

At least two other shear zones have been prospected by the main crosscut, but only one of these—about 300 feet from the portal—is now exposed. This is a narrow shear zone 6 to 8 inches wide striking 130° and dipping 53° NE. High gold values are reported from it although there is only a little visible quartz. To the southeast this vein bends to the south and loses its identity as a vein altogether.

WEBFOOT PROSPECT

A small prospect known as the Webfoot prospect is situated at an altitude of 3,925 feet near the lip of a cirque on the south side of Archangel Creek and about 1 mile south of the Fern mine. The property is believed to have been staked about 1917 and is now covered by two patented claims (see pl. 4). A strong vein trending nearly due north and dipping 33° to 40° to the west has been exposed for several hundred feet by open cuts on the surface and for about 300 feet underground by drifting. Throughout the 300 feet of exploratory drifting a width of 2½ to 4 feet of quartz, in places banded, is maintained. This is reported to be low-grade ore, but a large tonnage may justify mining operations. Further drifting and raising on the vein will adequately test the grade of ore. Some development work was carried out in 1947 and 1948, but the property was idle in 1949 and 1950.

KELLY-WILLOW PROSPECT

The Kelly-Willow prospect, also known as the Gold Center prospect (formerly the Brooklyn Development Co.), is located on the east side of upper Willow Creek valley. The property is said to have been located in 1909, but only sporadic work has been undertaken since the original discovery. There is almost no reference to this property in older literature. During 1946, 1947, and 1948 it was under lease and

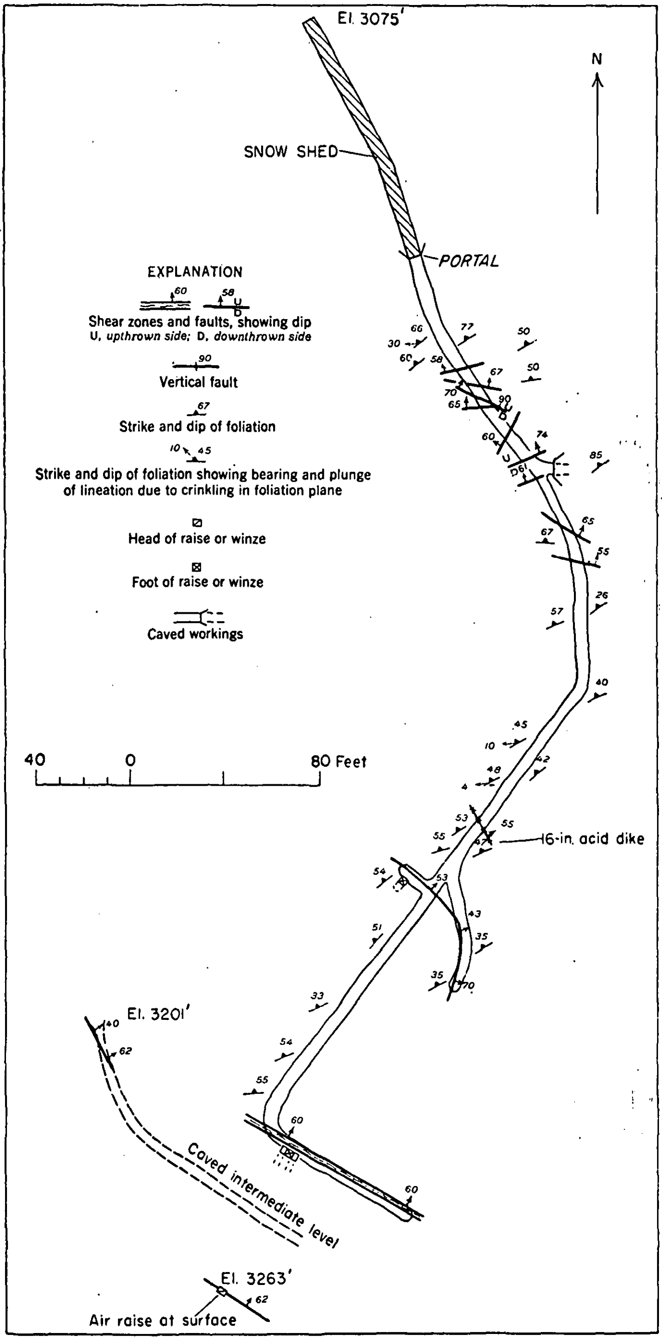

FIGURE 28.—Map showing workings of Thorpe mine.

option to the Kelly-Willow Co. of Seattle. The property is covered by four patented claims and one patented fraction (see pl. 4). Four tunnels and one inclined shaft prospect various shear zones on the property. Only a lower tunnel and an upper tunnel are now accessible. A Chilean mill and two small buildings in disrepair are on the property.

Good showings of ore were reported from a vein exposed in the uppermost tunnel located at 4,240 feet altitude, and in 1947 a crosscut at the mill level more than 400 feet below the upper workings was driven approximately 550 feet to intersect the downward extension of this vein (pl. 9). About 155 feet from the portal a strong shear zone showing mostly gouge material was intersected. This zone was drifted on for about 200 feet southward, but only sporadic, very narrow barren quartz stringers were encountered in a gouge zone 1 to 5 feet wide. This zone trends about 162° and dips on the average 45° SW.

Approximately 340 feet from the portal a second, narrower shear zone trending 170° and dipping 30° to 45° SW. was crossed. This zone was followed southward for nearly 500 feet. In only a few places is this shear zone more than a foot wide. It consists mainly of clay gouge and broken quartz diorite. Little or no quartz is present. At a point in this drift about 140 feet south of the main crosscut a test raise was driven for 25 feet on the shear zone but failed to encounter quartz.

A downward projection of the vein from the uppermost level, at an assumed dip of 40°, would intersect the mill-level crosscut approximately at the present face, but reliance on such a projection, equivalent to about 670 feet of dip slope, is particularly hazardous in the Willow Creek district where the quartz diorite is cut by many faults. Indeed, there is every indication from surface studies that a major fault does cut the vein exposed in the uppermost workings (see pl. 1). If this is a normal fault as seems likely, then one of the barren shear zones already intersected in the mill-level crosscut may represent the downward extension of the vein.

During 1948 some development work was done on the vein exposed in the uppermost tunnel. Here the vein trends 168° and dips on the average about 40° SW. (fig. 29). The thickness of quartz along the vein varies considerably. At its widest part in the underhand stope the vein is 4 feet wide and contains footwall, central, and hanging wall stringers of bluish-gray quartz each about 6 inches wide. It is here also that wet assays of $44 were reported in 1948 from narrow stringers of quartz. With one or two exceptions assays over the full width of the vein were very low, however.

It should be pointed out that the Kelly-Willow vein in the upper tunnel dips approximately with the slope of the mountain, and if it

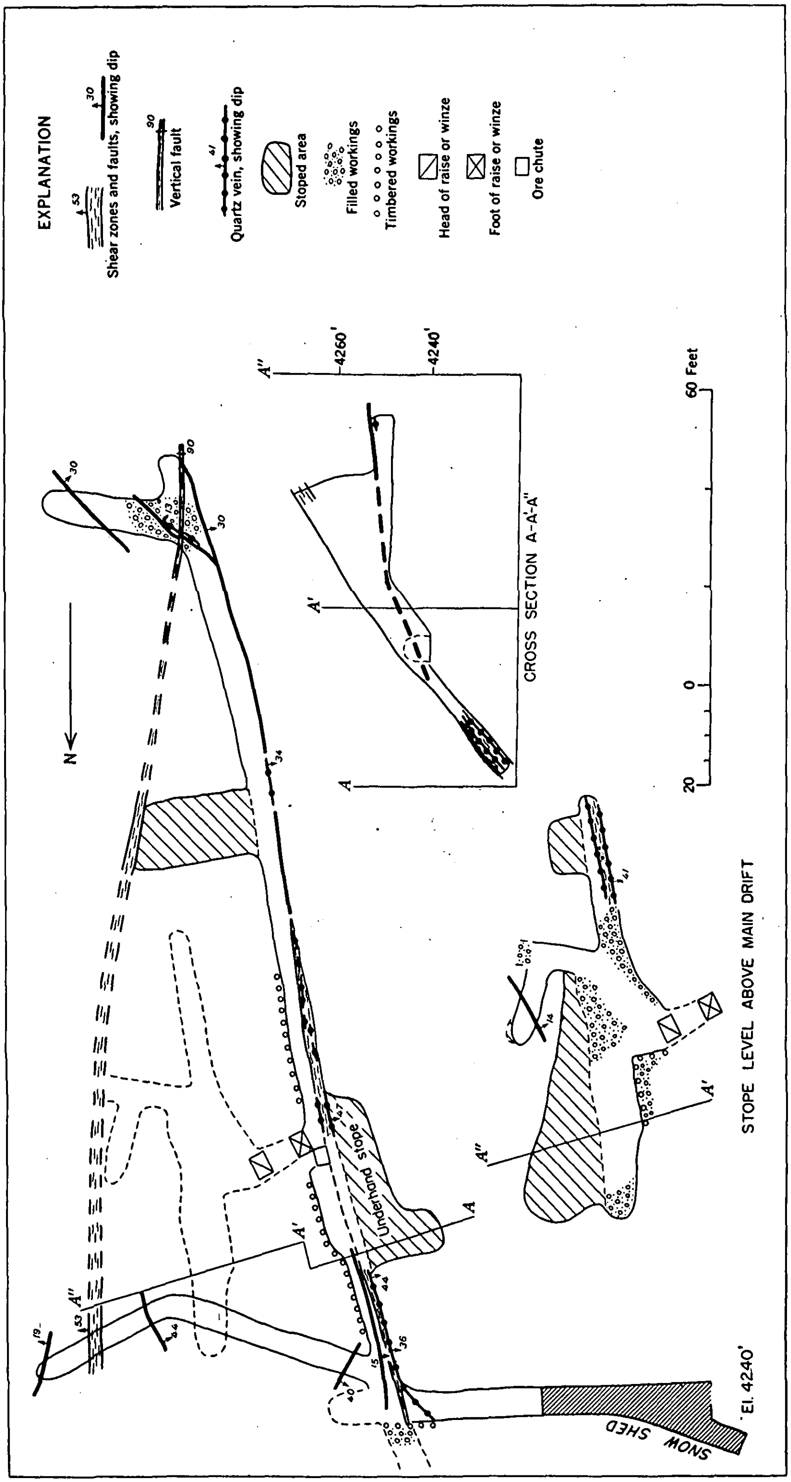

FIGURE 29.—Map showing upper workings, Kelly-Willow prospect.

should crop out near the top, the vein apex would probably be on ground now covered by patented claims of the Independence mine.

LANE PROSPECT

Four claims, known as the Glacier Claims, have been staked at the Lane prospect situated at 5,000 feet altitude at the head of Archangel Creek. A 20-foot tunnel has been driven by hand on an 8-inch vein composed of coarse, vuggy quartz containing numerous isolated pieces of free gold. Free gold also occurs as hairlike masses in pyrite, and in a gray-black sulfide. Assays of several hundred dollars have been made on a number of samples. The vein trends 150° to 165° and dips 35° to 38° SW. During the summer of 1950 a light single-track aerial tram was being installed by Jacob Lane, owner, prior to continuing development work.

HOLLAND PROSPECT

At the head of Purches Creek just north of the low divide between Purches Creek and Craigie Creek a composite quartz vein-pegmatite dike containing copper sulfides is exposed below the talus for about 50 feet. The vein is considerably disturbed, but it has a general strike of 128° and dip of 35° SW. It is about 8 feet wide and consists of a 6-foot central band of shattered milky to light-purple-colored quartz bounded by 12 inches of pegmatite on the hanging wall and 16 inches of pegmatite on the footwall. Between the pegmatite and central band of quartz is a 2 to 3 inch zone of strongly sheared cream-colored plagioclase feldspar. Quartz from the central band projects into this feldspar zone and is thus younger. The bounding pegmatite zones are composed largely of an intergrowth of feldspar and quartz. Pink feldspar and randomly oriented biotite plates as much as 2 inches in length are also conspicuous.

Pyrite, bornite, and chalcopyrite occur principally along the contacts of the central quartz band, but also as stringers and irregular masses in the central quartz. Small blebs of an unidentified mineral occur within the bornite. The presence of bismuth shown in spectographic analyses is believed to be due to this mineral. In the part of the vein now exposed, sulfide stringers are as much as 1 foot in length but do not exceed 2 inches in width. The amount of copper that might be recovered from this deposit appears to be exceedingly small.

Locally the quartz diorite country rock on the hanging wall side of the vein is shattered and contains thin seams of pyrite as much as one-eighth inch wide in narrow en echelon shears which appear to parallel the contact. These pyrite seams occur as far as 3 feet from the contact in places.

A small tunnel below the vein has been driven by hand for about 20 feet in quartz diorite but has not been extended far enough to intersect the vein.

OTHER MINES AND PROSPECTS

Several of the mines in the Willow Creek district have long been abandoned, or closed down for such a period as to be inaccessible now. This group includes the Martin, Gold Bullion, Lucky Shot, War Baby, and Talkeetna mines (pl. 1). All are described in older reports of the Geological Survey. The Talkeetna mine, now a part of the Fern Mining Co. holdings, was not an important mine in the district, but the Martin, Gold Bullion, Lucky Shot, and War Baby mines contributed a large part of the total gold production from this area. The Martin and Gold Bullion mines have long been abandoned, but in 1939 and 1940 old tailings at the Gold Bullion camp were cyanided and several thousand dollars worth of gold recovered. Until 1942 the Lucky Shot mine was one of the most important producing mines in the district, but there has been no activity since that date, and in 1950 only the main crosscuts were accessible.

Numerous small prospects are scattered throughout the mining district, but aside from those discussed above they have not been sufficiently prospected or are not well enough exposed to justify a description herein.

PLACER PROSPECTS

Some placer mining was carried on when the Willow Creek mining district was first opened up around 1900, and the gold recovered then was from these placers. However, there never was any large-scale placer mining, and interest in placers lagged considerably after the discovery of lode gold in 1906. Glaciation largely destroyed the possibility of successful placer mining, but two properties were being prospected in 1950. Grubstake Gulch heading in the mica schist has been the site of the most successful placer operations. At present 18 claims near its junction with Willow Creek are held by Lloyd Hill. Poorly sorted gravels on a high bench just east of the mouth of Grubstake Gulch yield some free gold on panning, but the numerous boulders will make placer mining difficult. 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 that could be mined successfully.

Wet Gulch, immediately west of Grubstake Gulch and tributary to Willow Creek from the south is also the location of several placer claims owned by Howard Brown. Assessment work was carried out in 1950 but the writer did not visit the prospect.

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