UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

GEOLOGICAL SURVEY
W. C. Mendenhall, Director

**Bulletin 849—C**

# THE WILLOW CREEK GOLD LODE DISTRICT ALASKA

BY

JAMES C. RAY

**Investigations in Alaska Railroad belt, 1931**

**(Pages 165–229)**

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1933

For sale by the Superintendent of Documents, Washington, D.C. - - - - - - - Price 20 cents

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## FOREWORD

By Philip S. Smith

To help the mining industry of Alaska and to assist in the development of the mineral resources of the Territory have been the prime motives of the Geological Survey's investigations in Alaska during the past 35 years, in which nearly one half of the Territory has been covered by its reconnaissance and exploratory surveys. It was natural, therefore, that the Alaska Railroad, when it undertook intensive consideration of the problem of finding tonnage that would increase its revenues, should look to the Geological Survey to supply technical information as to the known mineral deposits along its route and to indicate what might be done to stimulate a larger production of minerals and induce further mining developments and prospecting that would utilize its service. Realization of the need for this information had long been felt by the officials responsible for the operation of the Alaska Railroad, and the need had been partly supplied by the Geological Survey, but funds to carry through an extensive inquiry of this sort had not been available until 1930, when a special committee of the Senate, composed of Senators Howell, Kendrick, and Thomas, visited Alaska, studied some of the railroad's problems, and successfully urged Congress to grant it $250,000 for investigations of this kind.

On the invitation of the Alaska Railroad the Geological Survey prepared various plans and estimates for the investigations that appeared to be most likely to contribute the desired information as to the mineral resources. Selection of the problems to be attacked proved difficult, because the choice necessarily was hedged about with many practical restrictions. For instance, each project recommended must give promise of disclosing valuable deposits—a requirement that was impossible to satisfy fully in advance, as it involved prophecy as to the unknown and undeveloped resources. Then, too, it was desirable that the search should be directed mainly toward disclosing deposits which if found would attract private enterprises to undertake their development in the near future. Finally, some of the deposits that might be worked profitably did not appear likely to afford much tonnage to be hauled by the railroad. Under these limitations it should be evident that the projects that could be recommended as worth undertaking with the funds available by no means exhausted the mineral investigations that otherwise would be well justified. In a large sense, all of Alaska may properly be regarded as indirectly contributory to the welfare of the railroad, but even in that part of Alaska contiguous to its tracks there are large stretches of country that are entirely unexplored and large areas that have had only the most cursory examination. Although areas of this sort might well repay investigation, they were excluded from the list of projects recommended because they were not known to contain mineral deposits of value, and it therefore seemed better to make the selection from other areas that had been proved to hold promise. Furthermore, several areas within the railroad zone were excluded because their value was believed to lie mostly in their prospective placers, which would not yield much outgoing tonnage; others because their lodes carried mainly base metals, for which development and the recovery of their metallic content in a readily salable condition were relatively expensive; and still others because their resources consisted mainly of granite, building stone, or some other product for which at present there is only a small local demand.

After careful consideration ten projects were selected, and the funds required for undertaking them were made available. The projects that were selected involved the examination of two areas principally valuable for their coal (Anthracite Ridge and Moose Creek), five areas likely to be principally valuable for gold (Fairbanks, Willow Creek, Girdwood, Moose Pass, and Valdez Creek), and three areas whose lodes consisted mainly of mixed sulphides (the Eureka area in the Kantishna district, Mount Eielson, formerly known as Copper Mountain, and the head of West Fork of Chulitna River). The general position of these different areas is indicated on the accompanying diagram (fig. 1). A general study of the nonmetalliferous resources of the entire region traversed by the railroad was included in the projects to be undertaken, but the results obtained were not such as to permit adequate determination of their extent at this time.

Examinations were made in the field in each of the selected areas, all the known prospects and mines being critically examined and sampled so far as time and other conditions permitted. The records thus obtained, together with all other information bearing on the problems, were then subjected to further study in the laboratory and office, in the course of which other Geological Survey specialists whose knowledge and experience could be of assistance were freely consulted. The outcome of all these lines of analysis has been the reports which make up this volume. Although each chapter is presented as embodying the latest and most authoritative information available regarding the districts and properties described up to the time field work in them

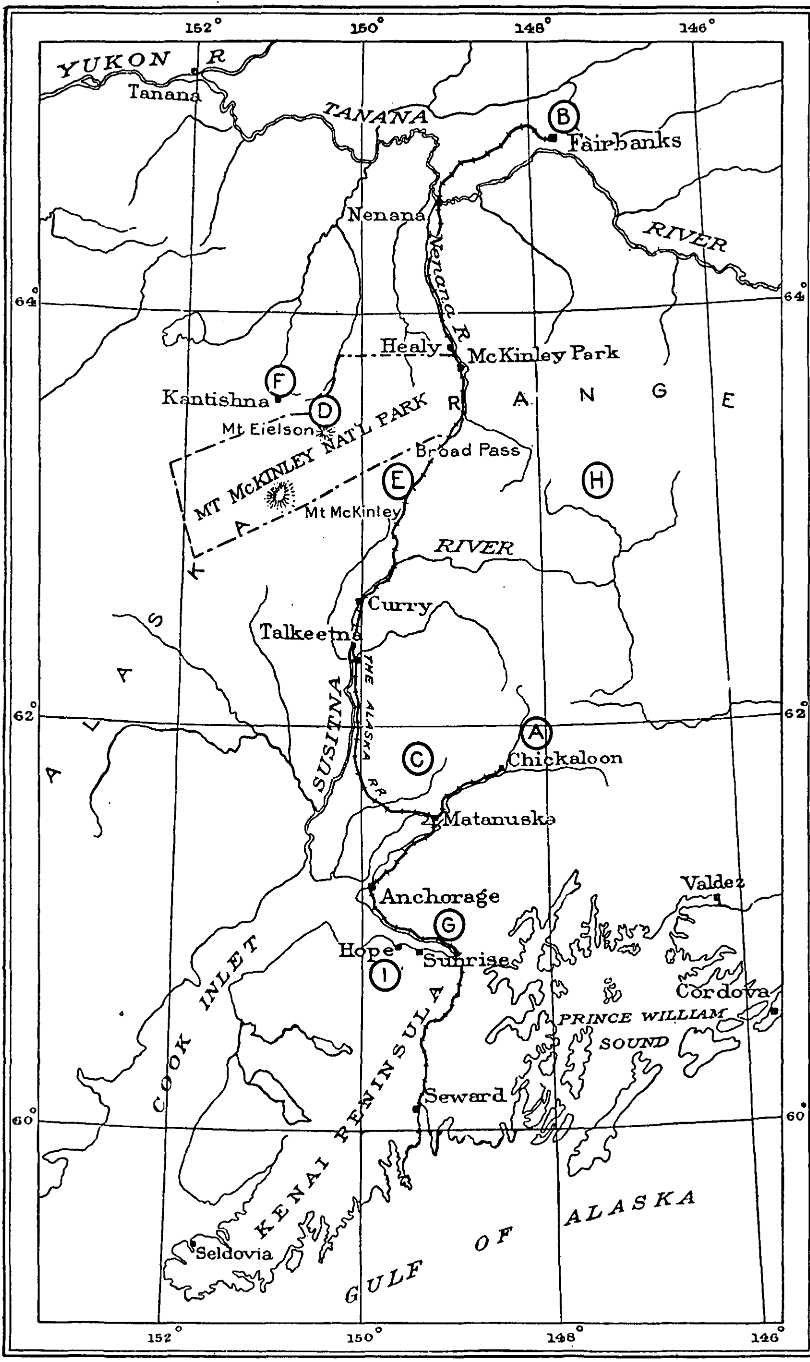


FIGURE 1.—Index map showing areas investigated in Alaska Railroad belt, 1931. A, Anthracite Ridge B, Fairbanks; C, Willow Creek; D, Mount Eielson; E, West Fork of Chulitna River; F, Eureka and vicinity; G, Girdwood; H, Valdez Creek; I, Moose Pass and Hope

was finished, the authors make no claim that all the results they have presented are to be regarded as final nor as solving all the problems that have arisen. Actually none of the mines have been developed to such an extent as to furnish all of the evidence desired to solve the problems involved. At none of the properties is any considerable quantity of ore actually "blocked out" in the engineering sense of that term, so that instead of specific measurements as to the quantity and grade of ore the different camps will yield, the Survey geologists and engineers have necessarily had to make numerous assumptions and be content with estimates and generalizations as to the potential resources. Furthermore, the work was planned so as not to invade the proper field of the private mining engineer in the valuation of individual properties, but rather to occupy the open field of considering the districts as a whole.

In two of the districts, Anthracite Ridge and Moose Creek, whose value lay in their prospective coal resources, the examinations that could be made by ordinary geologic means were not adequate to arrive at a final judgment of the resources of the area but pointed to the desirability of further tests by drilling. As a consequence additional exploration of these districts by means of diamond drilling was authorized, and this work was undertaken in the season of 1932. The results of these tests were not available at the time the manuscripts of the other reports were completed, and rather than delay their publication until the later reports could be finished and incorporated in the volume these reports have been omitted here and will be published later elsewhere.

This is not the place to summarize the detailed findings of the geologists as to the merits of the different districts, as those findings are explained in detail and summarized in the respective chapters. Suffice it to say here that on the whole the principal purpose of the investigations was carried through satisfactorily and that while the studies in some of the districts indicate that they hold little promise of extensive mineral development in the near future, others appear to encourage development under existing conditions, and still others seem to be worth development when some of the existing factors such as transportation or price of base metals are improved. That conditions which are now temporarily retarding the development of some of the deposits will become more favorable cannot be doubted. The entire region is becoming more accessible each year, and as a result costs are being lowered and experience is being gained as to the habit of the various types of deposits, so that the conclusions expressed in this volume as to the resources of the different districts should be reviewed from time to time in the light of the then current conditions.

# THE WILLOW CREEK GOLD LODE DISTRICT, ALASKA

By James C. Ray

ABSTRACT

The gold quartz veins of the Willow Creek district belong to the type of ore deposits that may be expected to continue downward for several thousand feet below the present surface. The veins occur in an essentially homogeneous quartz diorite intrusive mass, batholithic in form; therefore, the composition of the wall rock plays practically no significant part in the distribution of gold within the veins. The veins were formed partly as fissure fillings and partly by replacement of the wall rock along fractures and of fragments of wall rock caught between the fracture walls. Structurally the deposits are essentially composite lodes, although quartz lenses of considerable size have also been formed. Neither the maximum thickness of any one lode nor that of the mineralized zone appears to have been adequately determined in the mines of the district, because of lack of thorough crosscutting. Some of the lodes, as at the Fern mine, are known to be at least 24 feet thick, and quartz lenses as much as 14 feet thick have been mined in the War Baby, Gold Bullion, Lucky Shot, and Gold Cord mines.

There has been an apparent tendency for the ore shoots to form at and near the branching of major fractures within the mineralized zone. The principal mineralized zone, in which seven productive mines have been developed, has been proved to be at least 8 miles long. The ore extracted in the several mines has averaged from $25 to the ton in the Fern mine, at the northeast end of the proved zone, to $50 to the ton in the Lucky Shot, at the southwest end of the zone.

Numerous faults cut the veins into segments that are as much as 1,200 feet long. In the fault between the Lucky Shot and War Baby mines the horizontal displacement is about 600 feet along the strike of the fault.

Postmineral movements in the general plane of the lodes have developed slickensided walls which are not always the limiting boundaries of the ore, and lack of crosscutting during the course of exploration has undoubtedly left behind unsuspected valuable ore bodies.

The principal ore minerals are quartz, pyrite, arsenopyrite, tetrahedrite, galena, and native gold. Gold tellurides have been reliably reported to occur, but their presence was not detected in specimens studied by the writer. The gold was the last metallic mineral to be deposited. It occurs as isolated grains in the quartz and is associated with tetrahedrite and galena. The tetrahedrite, galena, and gold replace earlier sulphides, such as pyrite, sphalerite, and chalcopyrite, and are associated with a late microcrystalline quartz, which cements the earlier massive quartz and at many places forms the well-known ribbon structure.

Wall-rock alteration consists of chloritization, pyritization, sericitization, and ankeritization. The minerals accompanying the altered wall-rock and those in the ore are remarkably similar to those of the famous Mother Lode and Grass Valley districts in California. A further similarity to the Grass Valley veins is the irregular pinching and swelling of the lode and the irregular distribution of ore shoots. In Grass Valley barren zones were encountered, some of which persisted for as much as 800 feet down the dip of the veins, yet exploration has resulted in profitable mining down to 7,000 feet on the dip. Within this great distance there is no apparent change in the type of minerals that were deposited from the heated solutions, and similar conditions are expected to prevail also in the Willow Creek district.

The outlook for the future of the Willow Creek district is therefore promising, for it is believed that ores of the type and tenor so far mined should persist to depths far below any that have so far been reached. There is also a likelihood that many other valuable veins still remain to be discovered.

## INTRODUCTION

Though the outgoing tonnage from a gold district is necessarily small, there is a considerable quantity of ingoing freight to an active gold camp, such as mining machinery and mine supplies, fuel, building materials, and a never-ending flow of provisions. The transportation of persons to and from operating mines also furnishes considerable revenue to a railroad, and the stimulation of local agricultural activity consequent upon furnishing the camp with such supplies as can be grown locally adds to this revenue. As a result of the present low prices for the base metals, search for deposits containing them is not likely to lead to successful development. However, interest in the search for gold lodes has been stimulated, and it is believed that the possible development of such lodes in the vicinity of the Alaska Railroad may materially increase the tonnage handled.

## ACKNOWLEDGMENTS

During the course of the field work the writer was visited in the district by W. C. Mendenhall, Director; P. S. Smith, chief Alaskan geologist; and S. R. Capps and D. F. Hewett, geologists; all of the United States Geological Survey, whose interest and helpful suggestions he wishes to acknowledge. He is also especially indebted to Mr. Hewett for a critical reading of the manuscript of this report.

Workers and residents in the Willow Creek district, without exception, extended many courtesies which facilitated the field work. The writer wishes to express special thanks to W. E. Dunkle, Mr. and Mrs. T. S. McDougal, C. W. Isaacs, Charles Bartholf, Sydney Black, Q. A. Pyle, Mr. and Mrs. Clyde Thorpe, Herman Kloss, Ed Holland, and Mrs. W. S. Horning, for their generous assistance; also to J. M. McDonald, of Seattle, for maps and cross sections of the Independence and Martin mines.

The writer has drawn freely upon earlier publications on the Willow Creek district in order that this report may present a complete general picture. Further details, especially those concerning the general geology and other subjects not closely related to the mineral occurrences, will be found in the reports listed below, particularly Bulletin 607.

Becker, G. F., Reconnaissance of the gold fields of southern Alaska, with some notes on general geology: U.S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 1–86, 1898.

Eldridge, G. H., A reconnaissance in the Sushitna Basin and adjacent territory, Alaska, in 1898: U.S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 1–29, 1900.

Mendenhall, W. C., A reconnaissance from Resurrection Bay to Tanana River, Alaska, in 1898: U.S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 265–340, 1900.

Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna Basins, Alaska: U.S. Geol. Survey Bull. 327, 71 pp., 1907.

Katz, F. J., A reconnaissance of the Willow Creek gold region: U.S. Geol. Survey Bull. 480, pp. 139–152, 1911.

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

Capps, S. R., Gold mining in the Willow Creek district, Alaska: U.S. Geol. Survey Bull. 642, pp. 195–200, 1916.

Capps, S. R., Gold lode mining in the Willow Creek district, Alaska: U.S. Geol. Survey Bull. 692, pp. 177–186, 1919.

Chapin, Theodore, Lode developments in the Willow Creek district, Alaska: U.S. Geol. Survey Bull. 712, pp. 169–176, 1920.

Chapin, Theodore, Lode developments in the Willow Creek district, Alaska: U.S. Geol. Survey Bull. 714, pp. 201–206, 1921.

Capps, S. R., Geology and mineral resources of the region traversed by the Alaska Railroad: U.S. Geol. Survey Bull. 755, pp. 73–150, 1924.

## LOCATION AND AREA

The Willow Creek district is in the southwestern part of the Talkeetna Mountains, south-central Alaska, about 20 miles north of Knik Arm, a northeastward extension of Cook Inlet. It is easily accessible by automobile road from Wasilla, a small town on the Alaska Railroad about 40 miles north of Anchorage. The district is about 16 miles long from east to west, 6 to 8 miles wide, and includes an area of about 112 square miles. It extends approximately from latitude 61°40′ to 61°50′ and from longitude 149°5′ to 149°30′.

## EARLY EXPLORATIONS

So far as known the English navigator Cook was the first to chart the shores of Cook Inlet, in the year 1778. The Susitna Basin, however, was not explored until 1834, when the Russian Vassili Malakoff ascended the river. The discovery of gold on Turnagain Arm in 1888 led to further exploration of the Susitna and Matanuska Basins.

In 1895 G. F. Becker[1] visited several localities on Cook Inlet and studied the geology and mineral resources. The discovery of gold in the Klondike region in 1898 stimulated interest, and systematic surveys were begun. In 1898 G. H. Eldridge[2] and Robert Muldrow, of the United States Geological Survey, made a reconnaissance of the Susitna River and the head of the Nenana River. In the same year W. C. Mendenhall,[3] cooperating with a War Department expedition in charge of Capt. F. W. Glenn, ascended the Matanuska River to its head and crossed the broad basin to the northeast as far as the Delta River.

Not until 1906 was any extensive knowledge of the geology of the southwestern part of the Talkeetna Mountains gained. In that year T. G. Gerdine and R. H. Sargent carried a topographic reconnaissance survey around the Talkeetna Mountains, and Sidney Paige and Adolph Knopf[4] mapped the geology of the area surveyed. This work revealed the intrusive and probable batholithic character of the quartz diorite massif that comprises the greater part of the Talkeetna Mountains. During the same summer Paige spent a few days in the Willow Creek district and classified the rocks into the three main groups which are still recognized. In 1910 F. J. Katz[5] and Theodore Chapin, after work in the Matanuska coal field, made a short trip into the district, as a result of which the economic developments up to that time were described and some additions were made to the geologic map of Paige and Knopf.

The most comprehensive survey of the Willow Creek district was made by Capps[6] in the summer of 1913. His work included the first complete geologic map of the district, on a scale of 1 mile to the inch, based upon the excellent detailed topographic map by C. E. Giffin and R. H. Sargent. Capps' report is still the most authoritative and comprehensive statement of the general features of the district, though obviously many of the details of mining developments have changed greatly in the ensuing 20 years.

In 1918 Chapin[7] made a short visit to the district and in his report stated his observations of the general geology with reference to the gold lodes.

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[1] Becker, G. F., Reconnaissance of the gold fields of southern Alaska, with some notes on general geology: U.S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 1–86, 1898.

[2] Eldridge, G. H., A reconnaissance in the Sushitna Basin and adjacent territory, Alaska, in 1898: U.S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 1–29, 1900.

[3] Mendenhall, W. C., A reconnaissance from Resurrection Bay to Tanana River, Alaska: Idem, pp. 265–340.

[4] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna Basins: U.S. Geol. Survey Bull. 327, 1907.

[5] Katz, F. J., A reconnaissance of the Willow Creek gold region: U.S. Geol. Survey Bull. 480, pp. 139–152, 1911.

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

[7] Chapin, Theodore, Lode developments in the Willow Creek district: U.S. Geol. Survey Bull. 712, pp. 172–173, 1920.

Subsequent Geological Survey publications contain many references to the district, including tables of yearly production and accounts of the opening of new properties in the area.

## PRESENT INVESTIGATION

The field work of the present investigation covered the period from June 9 to September 23, 1931. It was deemed expedient to devote the greater part of the time available to a study of the operating properties where the vein structure and mode of occurrence of the ores could be observed to the greatest advantage. Consequently field work was largely confined to the Lucky Shot and War Baby mines, on Craigie Creek; the Gold Cord mine, on upper Fishhook Creek; the Mabel mine, on lower Reed Creek; the Fern mine, on Archangel Creek; and the Gold Mint mine, on the upper part of the Little Susitna River.

Other lode properties from which gold has been produced but which are now inactive are the Gold Bullion, which tops the high ridge between Craigie Creek and the head of Willow Creek; the Martin and Independence mines, on upper Fishhook Creek; and the Talkeetna mine, on Fairangel Creek. The old workings at these properties are now caved or filled with water to such an extent that detailed examination is difficult or impossible. The writer has therefore drawn his information regarding these inactive properties mainly from previously published data and from personal communication with those familiar with the properties when they were in operation.

## PHYSICAL FEATURES

### TOPOGRAPHY

The Talkeetna Mountains occupy a region deeply scarred by glacial erosion. At elevations above 2,500 feet the relief assumes proportions of rugged grandeur. Typical U-shaped glacial valleys separate the ridges, which in turn are deeply scaloped by closely spaced glacial cirques. Lateral moraines extend high on the valley walls, at many places forming two or more benches. Postglacial talus overlaps the upper edges of the glacial fill, thus further obscuring the underlying formations. Within the Willow Creek district proper the elevation ranges from 1,500 feet in the valley of the Little Susitna River to 6,000 feet at the crest of the highest peaks in the northeastern part. Farther northeast, beyond the limits of the district, elevations of 8,000 feet are reached. Above the lateral moraines and talus slopes rise precipitous cliffs and narrow ridges whose saw-toothed edges and craggy pinnacles exhibit many grotesque silhouettes.

In the western part of the Willow Creek district the bold and precipitous ridges change abruptly to greatly modified forms. Here the west front of the Talkeetna Mountains descends gently and disappears beneath the glacial debris of the Susitna Valley. The westward-trending ridges and spurs have been rounded off by a great ice flow, which at one time filled the Susitna Valley to a depth of 2,500 feet or more. In striking contrast to the gentle slopes of the west front is the steep south front of the Talkeetna Mountains, just south of the Willow Creek district. Extensive east-west faulting and the steep southward dip of the Eocene sediments characterize the south face of the hills as they terminate along the Matanuska lowland, which was also covered by ice to a depth of more than 2,000 feet.

## CLIMATE

The Willow Creek district lies in the southwestern part of the Talkeetna Mountains and is about 120 miles from the open Pacific Ocean, but Knik Arm, extending northeastward from Cook Inlet, brings tidewater within 20 miles. This coastal influence modifies the temperature so that it is less extreme than that of interior Alaska, north of the Alaska Range, and also produces a moderately heavy precipitation both summer and winter.

The only climatic record available is that for Matanuska, on the Alaska Railroad a few miles from Knik Arm, which is summarized below.

*Summary of climatic record at Matanuska, Alaska, 1922–29*

[Latitude 61°30′, longitude 149°15′; elevation about 150 feet. Data collected at agricultural experiment station by United States Department of Agriculture]

| Year | Temperature (°F.) | | | | | Precipitation (inches) | |
|---|---|---|---|---|---|---|---|
| | Average for year | Highest | | Lowest | | Total for year [a] | Snowfall [b] |
| | | Amount | Date | Amount | Date | | |
| 1922 | 34.2 | 82 | July 25 | −22 | Jan. 28 | 15.25 | 39.5 |
| 1923 | 37.5 | 83 | July 24 | −19 | Jan. 1 | 12.94 | 55.0 |
| 1924 | 35.1 | 78 | June 13 | −32 | Dec. 13 | 13.70 | 46.7 |
| 1925 | 35.4 | 77 | July 22 | −30 | Jan. 19 | 18.31 | 50.6 |
| 1926 | ------ | 84 | June 17 | −14 | Feb. 24 | 13.30 | 22.1 |
| 1927 | 33.4 | 77 | July 6 | −22 | Nov. 29 | 11.25 | 52.7 |
| 1928 | 37.0 | 84 | June 8 | −15 | Nov. 26 | 16.07 | 55.0 |
| 1929 | 36.5 | 78 | Aug. 2 | −30 | Dec. 31 | 16.56 | 29.6 |

[a] Includes snowfall.
[b] Divide by 10 to convert to approximate equivalent in water.

It may be assumed that climatic conditions are nearly the same at Matanuska and Wasilla, but the mountainous Willow Creek district has considerably more precipitation, and a larger proportion of that precipitation falls in the form of snow.

## VEGETATION

The entire mineralized portion of the Willow Creek district lies above timber line, which in this region is at an elevation of approximately 1,800 feet. Even scrub alder and willows capable of furnishing a meager supply of firewood to the prospector are found in few places in the district above 2,500 feet.

Immediately west of the district spruce and birch grow in abundance on the low glacial benches and lower slopes of the eastward-rising mountains, and cottonwood grows along the streams. Birch is an excellent firewood but on account of its greater weight is seldom transported into the district. Spruce furnishes the timber supply for the mines.

A variety of forage grass known as redtop, bracken ferns, and a profusion of wild flowers begin a luxuriant growth as soon as snow leaves the ground in the spring. Forage for pack horses is abundant by the middle of June and remains plentiful until the redtop is cut down by frost late in September. Peaty accumulations are forming in some of the high valley flats.

## POPULATION

Knik, a village on the northwest shore of Knik Arm, was the center of supplies for the Susitna and Matanuska Valley regions for many years. By 1913 its combined population, native and white, was 118, and it contained stores, road houses, a church, and a schoolhouse.

In the summer of 1917 the Alaska Railroad was extended as far north as Talkeetna, and villages sprang up at Matanuska and Wasilla. Matanuska became a junction for the branch railroad running up the Matanuska Valley to the coal fields, and Knik sank into oblivion. Wasilla became the center of distribution for the Willow Creek district, and a wagon road was built which joined the old trail from Knik near the point where the Little Susitna River leaves the Talkeetna Mountains. With the advent of the railroad and the establishment of an agricultural experiment station at Matanuska the tillable lands were homesteaded and the rural community grew until, in 1930, the census for the Wasilla district showed a population of 460.

During 1931 there were as many as 120 men employed regularly at the operating properties of the Willow Creek district, and other men were in the hills doing assessment work or prospecting.

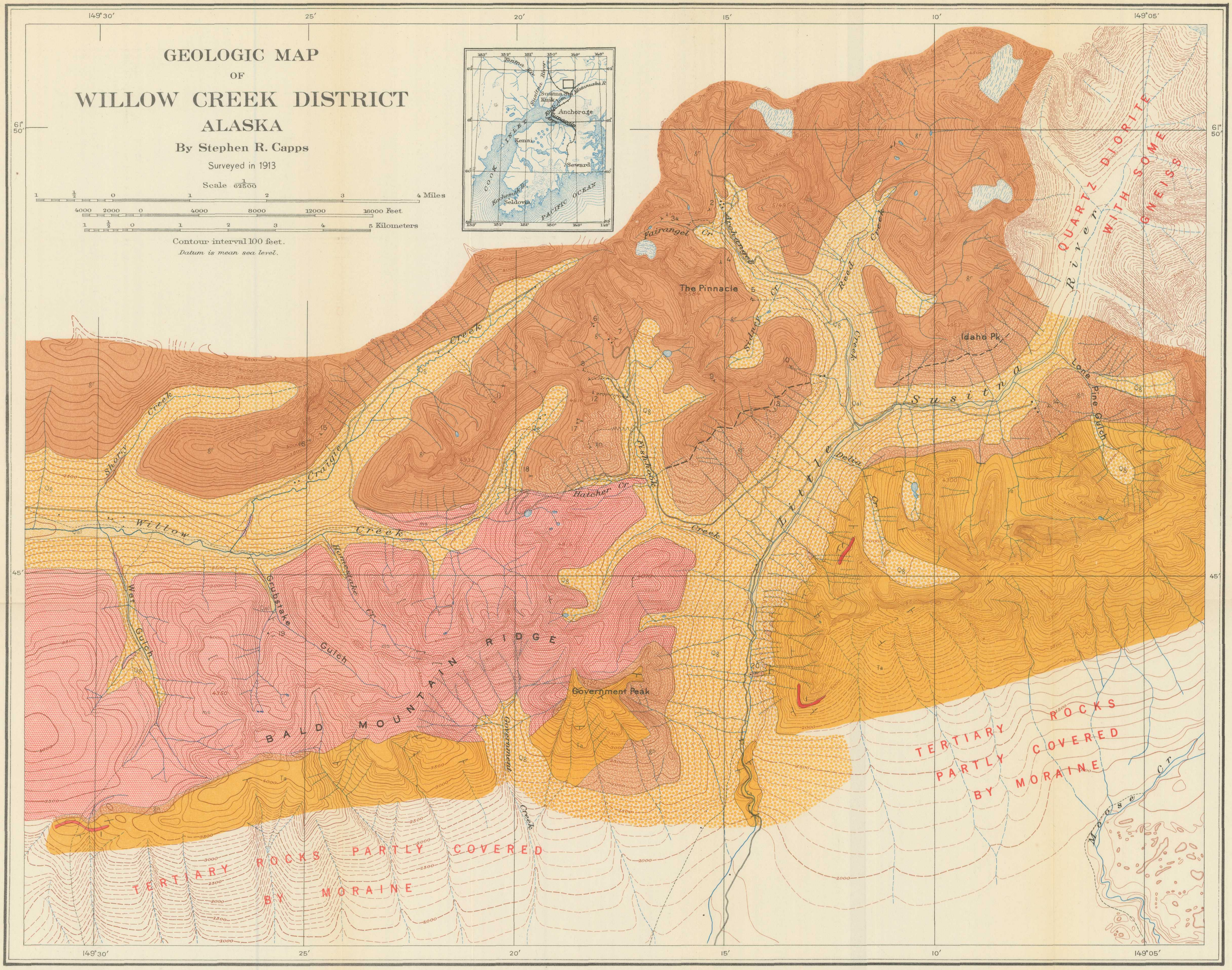
## ROUTES OF TRAVEL

Until the opening of the Alaska Railroad north of the Matanuska River all supplies were transported into the Willow Creek district over wagon road and trail from Knik. Although Knik was situated on Knik Arm, at the head of Cook Inlet, the water at this place is so shallow that landing could be made only by small boats at high tide, so that formerly, even during the open season, practically all travelers by ocean steamer to Knik landed at Knik Anchorage, opposite the present town of Anchorage. During about half the year the upper part of Knik Arm is closed to navigation by ice.

At the present time the Willow Creek district is readily accessible from Wasilla, on the Alaska Railroad, by an excellent automobile road. During the summer three automobile passenger stages and freight trucks make daily trips from Wasilla to all points in the district. One through passenger train and one through freight train make the trip from Seward to Fairbanks each week. Special gas-car service can be arranged with the railroad at any time. Two air-transport companies operate from Anchorage.

The automobile road from Wasilla, running northeast, ascends the gentle slopes of the Matanuska Valley and enters the Talkeetna Mountains through the picturesque gorge of the Little Susitna River. About 16 miles from Wasilla, at the junction of Fishhook Creek with the Little Susitna, is Fishhook Inn, a road house where accommodations may be obtained and from which automobile roads radiate to different parts of the district. The road along the west bank of the Little Susitna River crosses Reed Creek near its mouth and continues up the river 2½ miles farther to the mill on the Gold Mint property. A road starting a quarter of a mile above Fishhook Inn ascends the steep glacial fill on the west slope of the Little Susitna Valley for about a mile in a northerly direction; thence one branch continues northward up the valley of Reed Creek to Archangel Creek and on to the Fern mine, on upper Archangel Creek; the other branch doubles back around the mountainside into the hanging valley of Fishhook Creek and continues up that stream to the Gold Cord mine. From upper Fishhook Valley a road ascends Hatcher Creek, crosses the divide at an elevation of about 4,000 feet, and descends to upper Willow Creek, thence in a westerly direction skirts the mountain side and enters the valley of Craigie Creek near the Lucky Shot mine. From the Lucky Shot mine this road runs northeast up Craigie Creek to the camp of the Marion Twin Mining Co., on the headwaters of Craigie Creek. From the Lucky Shot camp a road has been built westward down Willow Creek to the Lucky Shot sawmill, a distance of 6 miles. The roads to the upper Little Susitna River and to Reed, Archangel, and upper Fishhook Creeks are closed during the winter and spring by snow.

A winter road enters Craigie Creek from the station of Willow, on the Alaska Railroad about 30 miles northwest of Wasilla, and connects with the Lucky Shot sawmill road. During the summer of




Topography by Alaskan branch
C. E. Giffin and R. H. Sargent, topographic Engineers
Control by C. E. Giffin
Geodetic position based upon data
by Coast and Geodetic Survey
Broken lines represent approximate topography
Surveyed in 1909-1913
Culture revised by J. C. Ray, 1931

1931 this road was improved, and it was expected that by the summer of 1932 it would be ready to serve as an all-year automobile or tractor road into Craigie Creek, thus obviating the present heavy ascent into Craigie Creek and the headwaters of Willow Creek by way of the steep Hatcher Creek route.

## SPECIAL FACTORS AFFECTING MINING

As the physical features, population, and routes of travel of the region have a direct bearing on mining developments, the more important of these factors will be considered here in further detail.

### OPEN SEASON

The climate exerts considerable influence on prospecting and mining in the Willow Creek district. The season when the uplands are free from snow is short, extending only from the middle of June to the later part of September. During the winter the snow obscures outcrops and renders travel over the steep trails from mine camps to the mine openings high up on the mountain sides both difficult and dangerous. It is difficult also to keep wagon roads open during the winter and spring on account of drifting snow and snowslides.

All outside construction must be completed during the open season. The winter is no more rigorous than in the mining regions of central Canada, but adequate camp facilities should be completed by September 1, so that, as far as possible, physical conveniences are provided and discomforts minimized. Proper housing and building construction are matters of great importance and should receive skilled attention by any company undertaking continuous mining work in this district. Only one company, so far, has constructed a camp that combines protection against the prevailingly low winter temperature, economy in heating, and conveniences such as showers and laundry and toilet facilities. The Willow Creek Mines, Ltd., has built such a camp at the Lucky Shot mine, on Craigie Creek. It houses 100 men in three buildings—two dormitories that accommodate 40 men each and a combination cookhouse and dining room, the second story of which accommodates the mine and mill staff.

### WATER POWER

Mines and mills that depend on water power developed close by are deprived of that power with the freezing of the streams, usually in late October. It is possible that hydroelectric power could be generated throughout the year on the lower reaches of the Little Susitna River and on lower Willow Creek, which do not freeze solid.

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## UNDERGROUND WATER

No direct information is available regarding the amount of water that may be encountered in the course of sinking. Present developments in the district are carried on exclusively through adits, which are driven well above the valley floors. In the few winzes and shafts that have been sunk the water was handled by simple methods without much trouble or cost. It is probable that water in greater amounts will be encountered when the workings are carried below the level of the valley floors.

## TRANSPORTATION

Transportation is effected by boat from Seattle to Seward and over the Alaska Railroad from Seward to Wasilla or Willow. From Wasilla good automobile roads lead to all properties in the Willow Creek district that have reached the producing stage, and hauling is done by automobile truck and caterpillar tractor. Freight from Wasilla to the district can be contracted for locally at $15 to $25 a ton. At the present time all hauling over the road from Willow is done by the Willow Creek Mines, principally during the winter.

## LABOR AND WAGES

Little difficulty is experienced in obtaining locally or at Anchorage the necessary skilled and unskilled labor for the few mines now operating, but should there be call for many skilled miners it would probably be necessary to seek a source of supply much farther away, possibly in the States.

The wages paid in the district in 1931 for surface labor for a shift of 9 hours, with board, was $5. Other wages paid for a shift of 8 hours, with board, were as follows: Carpenters, blacksmiths, engineers, electricians, and machine men, $5.50; underground muckers and timbermen, $5; shifters, $6.

## TIMBER

Mine timber is obtained from the lowlands between the Little Susitna River and Willow Creek. Spruce is the only available wood suitable for this purpose. The supply in the vicinity of the Little Susitna River has been somewhat depleted, but the growth in the Willow Creek area is sufficient for many years. Spruce poles 6 inches and more in diameter at the small end can be obtained on contract for 15 to 17 cents a foot length, delivered at the mines. Some of the spruce trees are as much as 2 feet in diameter at the base and are suitable for rough sawed lumber. The Willow Creek Mines operates its own sawmill, on Willow Creek about 6 miles below the mine. Rough dimension lumber can be purchased from small mills in the vicinity of Wasilla, but finished lumber is best procured from Seattle in carload lots.

## GENERAL GEOLOGY

### PRINCIPAL FEATURES

The principal hard rocks exposed within the Willow Creek district are quartz diorite, probably of late Mesozoic age; very old mica schist of sedimentary origin, probably pre-Cambrian; a thoroughly cemented arkosic conglomerate, possibly of Cretaceous age, which is exposed at several localities along the southern limits of the granitic rocks; a series of early Tertiary sedimentary beds; and Quaternary glacial debris and more recent Quaternary stream deposits partly fill the valleys to varying depths. The areal distribution of these rocks is shown on plate 11.

The productive gold veins of the district occur within the quartz diorite, which occupies the northern half of the area. The quartz diorite is part of a large granitic mass that forms most of the Talkeetna Mountains. It grades locally into monzonite and in the eastern part into gabbro. This igneous mass is cut by dikes of dacite, dacitic aplite, and pegmatite. Flow structure and groups of sharply angular fragments of fine-grained dioritic rock included in the quartz diorite suggest that the portion in which they are found lies within the peripheral zone of the intrusive mass. The rock is much fractured and faulted as a result of stresses that were in operation before, during, and after the formation of the mineral deposits.

### SEDIMENTARY ROCKS

The sedimentary rocks and unconsolidated deposits of the Willow Creek district have been described in detail by Capps.[8] With the exception of the mica schist, they are all younger than the ore deposits and have little direct bearing on the economic development of the district.

The mica schist occupies the southwestern part of the Willow Creek area. Along its northern border it is brought into contact with the granitic rocks along a fault zone that apparently has a nearly vertical dip. This fault zone extends across the district from east to west, but no data have yet been obtained which indicate the direction of movement along the fault.

The schists lie mostly between Bald Mountain Ridge and Willow Creek, and according to Capps[9] are the oldest rocks in the Willow Creek district and probably also in the entire Talkeetna Mountain region. They consist of highly fissile, thoroughly foliated garnetiferous mica schists and chlorite-albite schists and are everywhere very uniform in appearance. The schists have been cut by dikes of vari-

[8] Capps, S. R., The Willow Creek district, Alaska: U.S. Geol. Survey Bull. 607, pp. 26–43, 1915.

[9] Idem, pp. 23–24.

ous kinds, some of which have themselves been metamorphosed along with the rocks which they intrude.

The sediments next younger than the mica schists, but separated from them by a very long period of time and by a profound unconformity, are the arkose, shale, and conglomerate of Eocene age, which occur along the south flank of the Talkeetna Mountains, as well as on part of the lowland immediately to the south, where they are concealed by later glacial deposits. These Eocene sediments are well indurated. The arkose beds, which form by far the largest part of the group, are composed of the disintegration products of the granitic mass, and in places are difficult to discriminate from it. The beds in general dip south away from the mountains, and are locally gently folded. At places they are interbedded with flows of basaltic lava. The group reaches a maximum thickness of several thousand feet.

The major geologic event of Quaternary time was the repeated invasion of this region by glacial ice. The glaciers by their erosion profoundly modified the physical appearance of the region and left extensive deposits of morainal material and outwash gravel, particularly in the lowland areas. Since the final withdrawal of the ice the streams have been engaged in restoring the normal gradient of their valleys, and moderate amounts of talus have accumulated from the weathering of exposed rock surfaces.

## IGNEOUS ROCKS

### QUARTZ DIORITE

#### DISTRIBUTION, AGE, AND CHARACTER

The quartz diorite, which occupies the northern half of the Willow Creek district, is part of the extensive granitic intrusive mass that forms the greater part of the Talkeetna Mountains. Geologic reconnaissances by Capps,[10] Paige and Knopf,[11] and Chapin[12] have determined the areal distribution of this mass and established its batholithic character.

Farther north and east, along the general course of the Talkeetna River, it intrudes early Jurassic greenstone[13] and other metamorphic rocks of early Jurassic age. Late Jurassic sediments contain erosional fragments of a similar quartz diorite and its differentiation

[10] Capps, S. R., The Willow Creek district, Alaska: U.S. Geol. Survey Bull. 607, 1915; Geology and mineral resources of the region traversed by the Alaska Railroad: U.S. Geol. Survey Bull. 755, pp. 83–84, 91–98, 1924; Mineral resources of the western Talkeetna Mountains: U.S. Geol. Survey Bull. 692, pp. 187–205, 1919.

[11] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna Basins, Alaska: U.S. Geol. Survey Bull. 327, 1907.

[12] Chapin, Theodore, The Nelchina and Susitna Basins, Alaska: U.S. Geol. Survey Bull. 688, 1918.

[13] Paige, Sidney, and Knopf, Adolph, op. cit., p. 20.

phases. The relation of the Talkeetna batholith to the Middle Jurassic sediments is uncertain. Until recently it was believed to be lower middle Jurassic. However, similar granitic rocks are now known to intrude Cretaceous sediments in the Alaska Range to the north. Scattered satellitic exposures of similar granitic rocks that lie between the two batholithic masses indicate that all may have had a common source, thus suggesting that the Talkeetna batholith was intruded during late Cretaceous or even early Tertiary time.

The Talkeetna massif is composed predominately of quartz diorite, but differentiation phases within the mass range from diorite to quartz monzonite, and some border phases have the basic quality of a gabbro. Within the Willow Creek district quartz diorite predominates. It varies from quartz-hornblende diorite to quartz-biotite diorite. It is in general coarsely crystalline and exhibits a speckled black and white pattern, except in the vicinity of the quartz veins, where the development of chlorite gives some parts a distinctly greenish tinge.

Marked parallelism of large individual crystals (phenocrysts) of hornblende and biotite occurs in the quartz diorite in many parts of the district. This parallelism was apparently developed as a result of movement of the magma during the incipient stages of crystallization and is called flow structure. It is generally developed in the outer zone of the intruding magma, and the direction of parallelism is believed to conform more or less closely to the boundaries of that magma.[14]

In some places the quartz diorite exhibits a concentration of the iron-bearing minerals (hornblende and biotite) into elongated lenses and bands called schlieren. Schlieren are also caused by movement in the marginal part of the magma during its cooling and crystallization and may be so well developed that the rock resembles a primary gneiss. Rock of this texture was observed cropping out near the upper adit of the War Baby mine, on Craigie Creek. (See fig. 25.) At this locality the coarsely crystalline quartz diorite has an outer zone of unknown width in which the hornblende and biotite exhibit marked parallelism. Microscopic study of a thin section of this rock shows that the early plagioclase crystals have been dragged and broken and that the fragments remain in rough alinement and are cemented in a finer groundmass of plagioclase, hornblende, and biotite. Only a little quartz is present in this outer zone, and there is no concentration of the iron minerals and no evidence of recrystallization. Within the outer zone occurs a sheet that shows distinctly

[14] Balk, Robert, A contribution to the structural relations of the granite intrusions of Bethel, Barre, and Woodbury, Vt.: Vermont State Geologist Fifteenth Rept., pp. 39–96, 1927; Primary structure of granite massives: Geol. Soc. America Bull., vol. 36, pp. 679–696, 1925.

gneissic structure. It is bordered by bands in which there is intense concentration of the iron-bearing minerals (schlieren), a noticeably increased amount of quartz, and some bornite. The primary minerals—hornblende, biotite, and plagioclase—show a slight alteration to sericite. The quartz is largely interstitial, and the presence of bornite is suggestive of a slight local concentration by magmatic water. Isolated nodules of bornite in the country rock have been reported from other parts of the district.

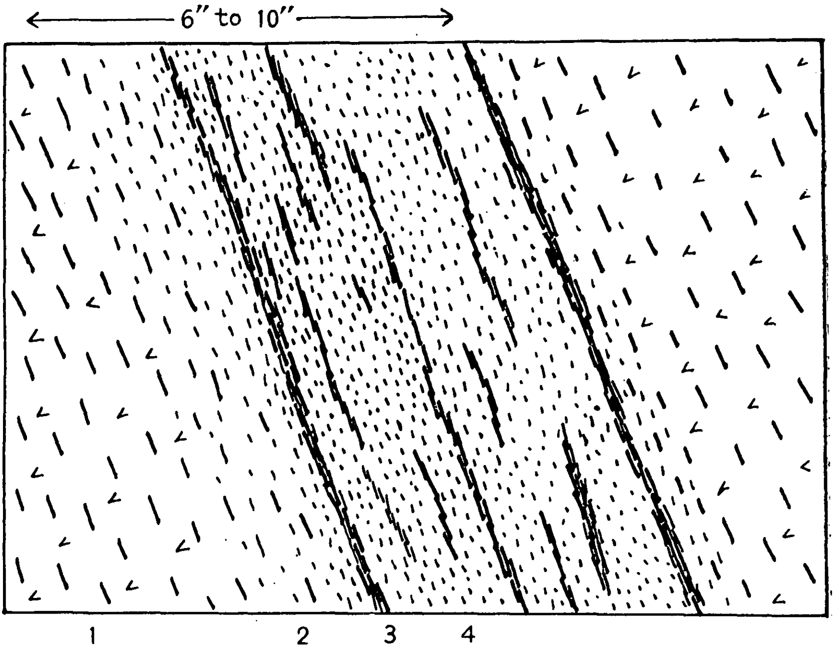



FIGURE 25.—Schlieren in rock near upper adit of War Baby mine on Craigie Creek. The flow structure is roughly parallel to major jointing in the quartz diorite country rock. The parallelism and concentration of hornblende and biotite, the broken and recemented plagioclase crystals, and the lack of recrystallization indicate movement during crystallization. 1, Coarse hornblende and biotite crystals parallel to trend of schlieren (3) ; 2, zone showing transition in flow structure from coarse grain to fine grain; 3, schlieren, continuous segregations of hornblende and biotite considerably altered to chlorite; 4, elongated lenses of hornblende and biotite in medium fine grained plagioclase and quartz (magmatic bornite is associated with the quartz).

Clusters of sharply angular fragments (xenoliths) of dark-gray fine-grained quartz diorite are included in the coarse quartz diorite at many localities in the district. They are embedded in the coarsely crystalline variety of the quartz diorite and are obviously fragments of an early crust of the invading magma. Although there is some evidence of resorption by the enclosing rock, the inclusions are generally sharply outlined, and their fragmental character is obvious. These fragments range in size from less than an inch to more than a foot. Their shapes are angular—generally flat and splintery.

Jointing in three directions (see pls. 12, *B*, and 16) is well developed in the quartz diorite throughout the district, except in the peripheral zone, where it has been obliterated by schistosity produced through later deformation. The strike and dip of the three joint planes are not constant throughout the district, possibly because of differential movement between the numerous fault blocks into which the area has been broken. The phenomena of primary gneiss exhibiting flow structure and schlieren and the presence of well-defined jointing suggest that the rock of the present erosional surface lay not far from the original periphery of the batholithic intrusion.

#### MINERALS

*Feldspars.*—Plagioclase, principally oligoclase and andesine, is by far the most abundant mineral in the quartz diorite. In the feldspar albite and carlsbad twinning predominate. Pericline and crossed lamellae are occasionally seen. A thin section of quartz diorite collected near the Fern mine, near the head of Archangel Creek, shows the plagioclase to range from basic oligoclase to acidic andesine. Capps[15] reports also albite and labradorite.

Orthoclase occurs but sparingly in the dioritic rocks of the Willow Creek district except in certain pegmatites.

Common alteration products of the feldspar are kaolinite (due to weathering) and, near the veins, sericite and secondary quartz.

*Hornblende.*—Next after plagioclase the greenish variety of hornblende is usually the most abundant constituent of the dioritic rocks, though biotite is second in some parts. The hornblende commonly occurs as fragments or poorly formed crystals, some of which exhibit twinning. In the primary gneiss it occurs also as irregular interstitial forms. Alteration products of the hornblende are chlorite, calcite, and occasionally epidote.

*Biotite.*—Biotite (brown mica) is in some parts the second important constituent of the quartz diorite, hornblende being almost absent. Alteration products are chlorite, sericite (white mica), and the iron oxides. In proximity to the veins or where included in vein material the biotite gives up its iron to form pyrite.

*Quartz.*—Quartz occurs in varying but always minor amounts, generally interstitially. It was the last of the principal minerals to crystallize.

*Chlorite.*—Although chlorite is at many places an abundant constituent, it occurs only as a secondary mineral. It commonly replaces biotite completely and assumes the platy form of the earlier mineral. Where it replaces hornblende it exhibits scaly aggre-

[15] Capps, S. R., The Willow Creek district, Alaska: U.S. Geol. Survey Bull. 607, p. 45, 1915.

gates. Epidote is seen here and there as an alteration product of hornblende.

*Accessory minerals.*—The accessory minerals include magnetite, titanite (and its alteration product leucoxene), ilmenite, apatite, and rutile.

### MAGMATIC DIFFERENTIATION

The process, usually crystallization, by which a homogeneous magma becomes separated into chemically unlike portions is called magmatic differentiation. Many magmas contain mineralizers, such as water vapor and other gases. The mineralizers are held in solution in the molten magma by pressure. Advancing crystallization of the magma drives before it solutions carrying sulphides, soluble metals, and excess remnants of silica and various salts left over from the minerals which have crystallized out to form a particular part of the rock mass.

The early dynamic history of an intrusive magma is also a factor in producing local differences in the chemical composition of the rock. At successive periods during the crystallization of the magma, fractures form in the brittle shell and may extend down to local reservoirs of still liquid magma at increasing depths from the periphery. As these local reservoirs may differ from each other and from the main mass of the magma, the dikes formed by the upwelling of the magma into the fractures generally represent the products of magmatic differentiation formed during successive stages of crystallization.

The dike rocks that now cut the quartz diorite of the Willow Creek district are evidence that magmatic differentiation had progressed through several stages and produced several types of rock, the result being a concentration of metals and mineralizers in sufficient quantity to produce valuable gold veins in a zone at least 8 miles long and of undetermined width.

### GABBRO

Rock that is probably a more basic phase of the normal quartz diorite intrusive mass occurs in the southeastern part of the Willow Creek district. This gabbroic rock was not seen by the writer. It is described by Capps [16] as follows:

> In the eastern part of the district here considered, near the southern edge of the area of intrusive rocks, there are local patches of intrusive rocks of gabbroic character. Some of these are massive and little altered; others have been severely metamorphosed and have become somewhat gneissic. A study of one of the more massive gabbros in thin section showed a few stout, irregular, nearly colorless augite-pyroxene prisms, some of which were partly altered to

[16] Capps, S. R., The Willow Creek district, Alaska: U.S. Geol. Survey Bull. 607, pp. 47–48, 1915.

hornblende, showing a granular nucleus of pyroxene surrounded by hornblende. Hornblende in brown to green anhedral prisms is more abundant than augite, and much of it is probably derived from the augite. The rock contains rounded areas composed largely of a mixture of serpentine and magnetite, which may represent altered olivine crystals. Another somewhat metamorphosed gabbro contains monoclinic pyroxene, probably augite, of a pale-green color, and plagioclase feldspars, dominantly andesine, though some orthoclase may be present. Accessory minerals are represented by apatite and magnetite.

### DIKES

Numerous igneous dikes cut the main mass of the quartz diorite batholith and also the old mica schist that lies in the southwestern part of the Willow Creek district. The dikes that cut the mica schist were not studied by the writer in the field. Microscopic study of thin sections from specimens collected by Capps shows that some of them are medium-grained quartz diorite. These are probably apophyses injected into the schist at an early period from the main mass of the adjacent quartz diorite intrusive. The dikes that cut the quartz diorite are of three distinct types—fine-grained dacite, medium-grained dacitic aplite, and coarsely crystalline pegmatite. These dikes are characteristic products of magmatic differentiation and were formed at temperatures considerably higher than those that prevailed during the formation of the intermediate-temperature veins. In the Willow Creek district these veins are known to cut the dacite and aplite dikes. Their structural relations to the pegmatite were not observed, but the veins probably were later than the pegmatite.

#### DACITE DIKES

Dark-gray fine-grained dacite dikes cut the quartz diorite in many places throughout the district. They have been seen in outcrops, though usually obscured by surface debris, and in most of the mine workings. They are from 1 to 4 feet in width and of unknown length. The dike in the Lucky Shot mine has been pierced by mine workings for a distance of more than 400 feet. If it is the same dike that has been encountered in the War Baby mine, on the opposite side of a transverse fault, it is continuous for at least 2,800 feet. The strike of these dikes is roughly parallel to that of the gold quartz veins. Where encountered underground the dip is opposite to that of the veins, and some of the dikes are offset by the veins. In a raise in the Lucky Shot mine a dacite dike was crossed by the vein without showing offset. Farther east in the same mine the dike is displaced by postmineral movement in the plane of the vein.

Detailed mapping of these dikes and their relations to the faults of the district might yield valuable information for locating faulted and lost segments of the gold quartz veins.

Microscopically the dacite consists of phenocrysts of long blunt prisms of greenish hornblende in a felsitic groundmass composed of tiny needles of hornblende and laths of plagioclase feldspar together with a little quartz and biotite. Magnetite is a prominent accessory mineral. Chlorite is the principal alteration product and

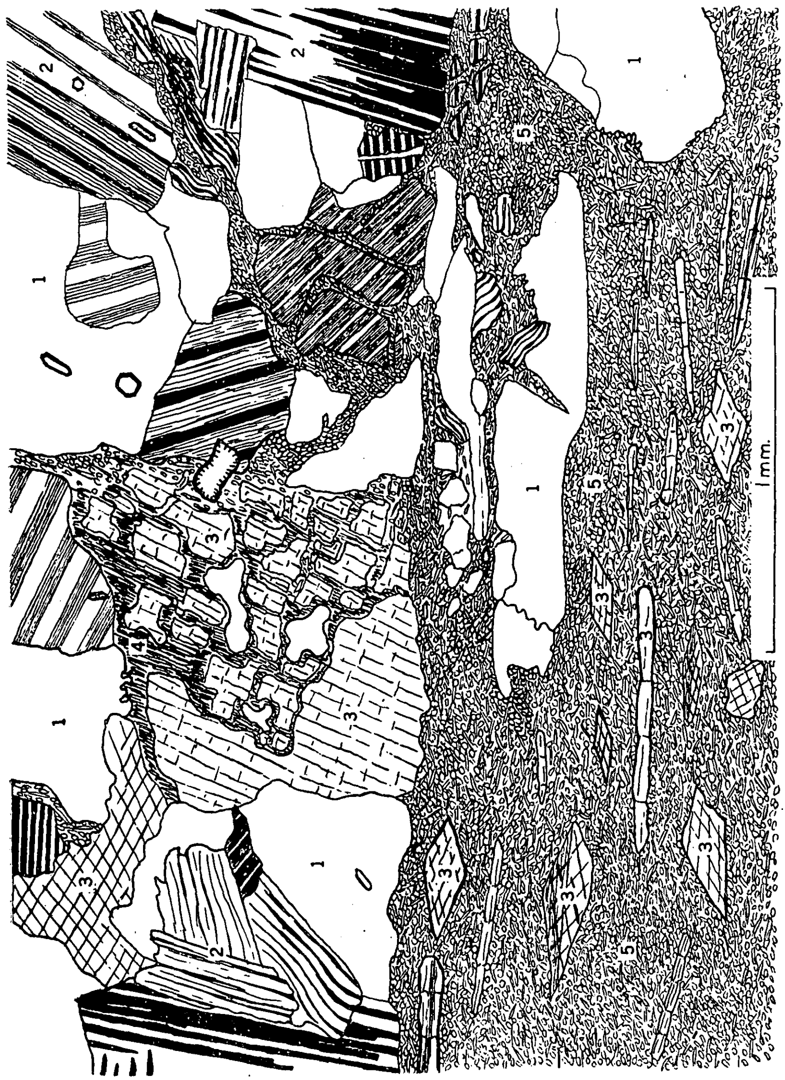



FIGURE 26.—Contact of dacite dike rock with quartz diorite country rock in Lucky Shot mine. 1, Quartz; 2, plagioclase; 3, hornblende; 4, chlorite; 5, microfelsitic groundmass of the dacite.

gives the rock a greenish tinge. The dike rock is composed of the same minerals as the main mass of the quartz diorite, the essential difference being textural rather than mineralogic.

The contact of the dacite dike with the quartz diorite country rock in the Lucky Shot mine is shown in Figure 26. For a distance of several millimeters from the actual contact the dacitic groundmass is microfelsitic, but toward the center of the dike it assumes a somewhat coarser texture. This change indicates the chilling effect of the country rock, but there is also some actual replacement of broken fragments along the fractured walls of the country rock.

### DACITIC APLITE DIKES

By far the largest dike in the Willow Creek district consists of a pale-greenish to white dacitic aplite of medium fine grain. It crops out near the contact between the quartz diorite and the mica schist, just west of the pass between the head of Hatcher Creek and Willow Creek, and extends eastward at least as far as Idaho Peak. The dike has a width of at least 100 feet where it is pierced by a tunnel on the Stiles property and is traceable for a distance of more than 3 miles. The major fault of the district (see pl. 11) apparently follows the general course of this dike. Narrow dikes of similar rock are cut by the quartz veins of the Talkeetna mine, on Fairangel Creek. (See p. 224.)

The only occurrence of the dacitic aplite fresh enough to permit fairly exact classification was found in a tunnel on the Stiles property, high on the northwest valley wall of the Little Susitna River and about halfway between the junction of Fishhook and Reed Creeks.

The rock has a medium fine grained holocrystalline texture and is composed essentially of angular quartz (one third) and well crystallized or partly crystalline altered plagioclase (two thirds), minor amounts of orthoclase, and a few scattered plates of muscovite. Apatite occurs as an accessory mineral. The feldspars are mostly altered to sericite and calcite, but unaltered portions display the characteristic polysynthetic twinning of the plagioclase. The presence of considerable ilmenite in the muscovite suggests that the muscovite is an alteration product of biotite. The calcite has a faintly greenish tinge, and the iron which produced this coloration was probably furnished by alteration of the biotite to muscovite. The predominance of plagioclase over orthoclase and the relatively large amount of quartz indicate that the rock is a dacitic aplite.

### PEGMATITE DIKES

Pegmatite dikes crop out sparingly in the quartz diorite country rock of the Willow Creek district. The maximum width of the dikes seen was 12 feet. In general the pegmatite is composed of coarsely crystalline pink orthoclase and glassy colorless quartz. Biotite is locally an abundant constituent of the rock. Texturally the pegmatite ranges from coarsely granitic to coarsely pegmatitic. In the coarser type the pink orthoclase prisms attain a length of 8 to

10 centimeters, and some biotite plates are 12 to 14 centimeters in diameter. Locally the pegmatite consists exclusively of glassy massive quartz cut by large plates of biotite.

One pegmatite dike high on the eastern valley wall of upper Purches Creek (Holland property) shows that reopening took place subsequent to the consolidation of the pegmatite, and massive glassy quartz was deposited between the fractured pegmatite walls to a maximum width of 4 feet. A second reopening fractured both the pegmatite and later quartz, and in these fractures chalcopyrite and bornite were deposited. (See fig. 27.) The copper-iron sulphides

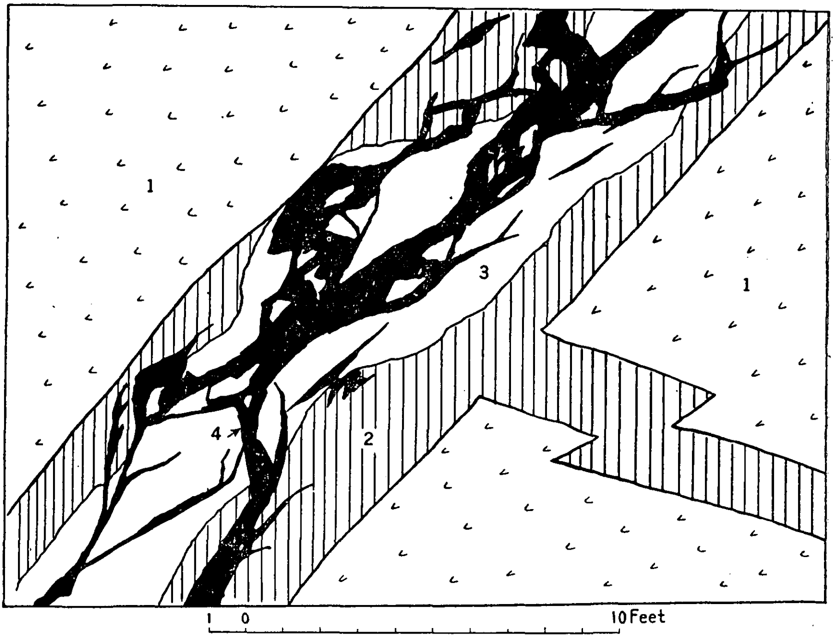



FIGURE 27.—Mineralized pegmatite dike on Holland property, on eastern valley wall of upper Purches Creek. 1, Unaltered quartz diorite country rock; 2, pegmatite; 3, massive glassy quartz; 4, chalcopyrite and bornite.

show not only as deposits in the clean-cut fractures but also as massive deposits replacing the orthoclase in the pegmatite. Three periods of mineralization are thus distinctly shown in the exposed part of this dike.

### LAVA FLOWS

Small lava flows are interbedded with the Tertiary sediments of the Willow Creek district. As their outcrops were not visited by the writer he has nothing to add to the description given by Capps.[17] The lavas do not appear to have played any part in affecting the commercially valuable mineral deposits of the district.

[17] Capps, S. R., The Willow Creek district, Alaska: U.S. Geol. Survey Bull. 607, pp. 48–49, 1915.

## STRUCTURE

Three sets of intersecting joints are well developed in the quartz diorite throughout the district. Two sets of these joints have a common strike in a general northeast direction, but they dip to the northwest and southeast respectively. The third set intersects the other two at nearly right angles. The joints are clearly exposed in the cliffs above Purches Creek, just north of the pass at the head of Craigie Creek. (See pl. 12, *B*.)

The field observations were not sufficient to determine whether the jointing was developed during the normal crystallization of the magma after it had come to rest (shrinkage jointing), whether it was the result of stresses brought into play by the mechanics of intrusive action, or whether it was due to stresses developed at a later period.

As some veins are formed along two or more of the joint planes the joints are older than the veins. The later, intermediate-temperature veins are formed in zones many of which coincide with the northwestward-dipping set of joints. (See pl. 16.)

The gold quartz veins of the Willow Creek district lie in zones of considerable lateral extent that give evidence of successive periods of reopening before the circulation of quartz-depositing solutions ceased. The principal mineralized zone is known to be at least 8 miles in length, extending in a northeasterly direction across the quartz diorite of the district. Structurally the fractures in which the veins were formed are typical of shear zones resulting from tensional stresses in an essentially homogeneous crystalline rock mass. Underground development in the Lucky Shot mine has demonstrated the presence of a main fracture with branches and offshoots that break away along the strike and dip. The length of the mineralized shear zones, their structure, and the minerals of the vein filling—all indicate fracturing to considerable depth. This fracturing must have resulted from stresses of more than local origin. If the intrusion of the diorite is assumed to have taken place during Cretaceous time, as in the Alaska Range to the north, then the fracturing may have been due to the stresses caused by the regional uplift that occurred during late Cretaceous time. The postmineral faults, which also cut the Eocene sediments, are correlated with the mountain-forming uplift that followed the deposition of these sediments.

The postmineral faults have been observed in many places and play an important part in the economic development of the district. They bear no recognized relation in strike and dip to any earlier structural features but seem to have been developed by stresses applied from a different direction and in a different manner from those that produced the shear zones in which the intermediate-temperature veins were formed. Within the quartz diorite area, where these faults have been encountered in mining operations, they strike generally northwest and dip prevailingly northeast or vertically. Movements along these faults have carried the block on the southwest in a northwesterly direction with respect to the block on the northeast.

Rotary movement has undoubtedly played its part in establishing equilibrium between the various fault blocks. In the quartz diorite radical divergence in the strike and dip of the joint planes on opposite sides of clearly defined faults is common. A good example of such rotary movement may be seen on the ridge northeast of the head of Craigie Creek, across the valley from the Gold Bullion workings. At this place the wedge-shaped block, lying between two faults that cut the ridge, has been rotated so as to bring one of the joint planes to the surface of natural erosion, where it is exposed as a smooth plane. The two faults here so clearly defined undoubtedly continue across Craigie Creek and have produced some of the displacements in the Gold Bullion mine. In some places changes in the dip of the veins are observable on opposite sides of a fault. This difference of dip is obvious in the Lucky Shot and War Baby veins, which are separated and displaced by such a fault. The dip of the veins in the Lucky Shot mine averages about 40°, whereas in the War Baby, on the other side of the block fault, the dip averages about 30°. Farther northeast, at the Gold Cord mine, the vein has the comparatively flat dip of 25° to 30°, and in the Fern mine, with several intervening block faults, the vein dips 45° to 50°.

Postmineral faulting, generally of minor amount, has also taken place within the individual fault blocks. This faulting was probably coincident with the transverse faulting and relieved stresses developed within the individual blocks during the period of major faulting. These small faults occur principally in the plane of the quartz vein or as step faults with dip normal to the vein and with the same general strike.

Another type of fault, well shown only in the Gold Cord mine though recognizable to a less degree in the Lucky Shot mine, shows a vertical dip and a strike roughly parallel to the vein. Rotary movement has taken place in the vertical fault in the Gold Cord, the displacement increasing toward the northeast.

That these minor faults are part of the general adjustment that took place during the period of postmineral faulting is shown by the fact that as they approach the general zone of transverse faults they bend back into them and generally "drag" the vein. They thus help to identify the direction of horizontal movement along the major faults. Both major and minor faults conform somewhat to joint planes.

Step faulting of the veins, as observed underground, is generally normal, shows a displacement seldom more than 2 to 4 feet, and was apparently the last faulting to disturb the veins. Postmineral movement in the plane of the veins has increased the thickness of ore lenses at many places by sliding one part of the vein down the dip over a lower part. This type of postmineral movement has reached the greatest intensity in the Fern mine, where one part of the lode has been reduced to rounded quartz fragments embedded in a ground-up mass of quartz and wall rock.

Along many of the faults the rock is intensely crushed and altered. Microscopic study of the less altered portions of the rock within one of these fault zones gives some insight into the character of the forces involved in the faulting. The quartz and plagioclase crystals are much broken and faulted by roughly parallel fractures, which are filled with kaolin and carbonates. Though the principal microscopic fractures cut indiscriminately across quartz and plagioclase, there is also slipping along the cleavage planes in the plagioclase. Fragments of individual crystals have been displaced by both types of fracturing.

The crushed and faulted condition of the individual crystals in these fault zones seems to indicate that they were formed under the action of compression. In contrast are the marked absence of such crushing in the wall rock of the intermediate-temperature veins and the shredded appearance of the rock of the veins of the composite-lode type, suggesting that those fractures were caused by shearing and that the component operating to cause them was tensional rather than compressive.

## GEOLOGIC HISTORY

The mica schist, the oldest rock in the Willow Creek district, is probably of pre-Cambrian age. The batholithic mass of quartz diorite is believed to have been intruded during late Cretaceous time. The fractures in which the mineral deposits were formed may have originated as a result of stresses caused by the regional uplift that took place in late Cretaceous time, after the quartz diorite had cooled. A long period of erosion followed the intrusion of the quartz diorite, during which the covering rocks over a large area were stripped from the granitic intrusion and the surface was reduced to one of fairly low relief. In the early part of the Tertiary period deposits were laid down on this eroded surface. These Eocene deposits as laid down consisted of mud, sand, coarse grit, and gravel; some of them contain abundant plant fragments and beds of coal. Interbedded with these sediments were occasional thin flows of basaltic lava. These Eocene rocks have all been eroded from the greater part of the Willow Creek district, but their contacts with the quartz diorite along the southern slopes of the basin of the Little Susitna River suggest that they once covered much of the area in which the igneous intrusive now forms the bedrock. The deposition of the Eocene sediments was followed by one or more periods of uplift which tilted, folded, and faulted the beds. Upon this complex composite mass the present-day topography was carved. Doubtless it had already reached a mature but rugged state of dissection at the time of accumulation of the great glaciers which filled all the large valleys. These glaciers profoundly modified the topography both by erosion and by the deposition of extensive morainal deposits, which obscure the underlying formations in the valleys and are themselves in places only slightly modified by streams of the present day.

## ECONOMIC GEOLOGY

The first mining activity in the Willow Creek district was the development of the placer gold deposits. Placer gold was discovered in the district in 1897, and between 1897 and 1905 gold worth several thousand dollars is reported to have been recovered from ground on Willow Creek and Grubstake Gulch. Only a small amount of placer gold has been produced in this district since 1905, and such prospecting as has been done gives little encouragement for any marked increase in output. Some placer gold is known to occur in a number of the small streams, but the presence of many large boulders renders operations unprofitable.[18] It has generally been considered that the placer gold in Willow Creek and Grubstake Gulch was derived from veins in the mica schist, which forms the greater part of Bald Mountain Ridge in the western part of the district south of Willow Creek.

The relatively small size and early exhaustion of the placer deposits led to the search for lodes. That this search has been successful is shown by the fact that gold worth more than $3,000,000 has been recovered from the lodes of the district since 1909.

All except one of the productive mines in the Willow Creek district have been developed in a zone that extends from the Lucky Shot mine on lower Craigie Creek, through the War Baby, Bullion, Independence, Martin, Gold Cord, Talkeetna, and Fern mines. (See pl. 11.) The presence of another zone is inferred from the vein developed in the Mabel mine, on lower Reed Creek, but its extent is undetermined beyond the limits of that property. A third zone is suggested by the occurrence of the vein at the Gold Mint mine, about 3½ miles east of the Mabel. The small amount of development on

[18] Capps, S. R., The Willow Creek district, Alaska: U.S. Geol. Survey Bull. 607, pp. 52–55, 1915.

other prospects scattered throughout the district is hardly sufficient to determine the magnitude and character of their fissures or the exact character of their vein filling.

## ORE DEPOSITS

### GENERAL CHARACTER

Four distinct types of veins can be distinguished in the region that include all of the ore deposits examined. Three of these types—namely, (1) pegmatitic, (2) high-temperature (hypothermal), and (3) medium-temperature (mesothermal) veins—are based upon the temperature at which it is believed the mineralizing solutions were introduced. The medium-temperature type is believed to be susceptible of further subdivision into two groups based on the mineral content and structure. Of these one, the older of the two (3a), is characterized by the presence of quartz in coarsely crystalline comb structure, associated with coarse crystals of galena, chalcopyrite, probably sphalerite (now largely removed by weathering), and coarse and irregularly distributed gold. This earlier gold quartz was deposited in lenses not more than 6 or 8 inches thick along two sets of slightly opened joint planes. No valuable ore shoots have been discovered in these veins. The younger group of medium-temperature veins (3b) were formed along shear zones of considerable magnitude whose origin was more profound than that of the joint planes. Quartz lenses in the shear zones attain a maximum thickness of 14 feet and have undergone reopening and movement during and since the several periods of quartz deposition. In these veins the gold is finely disseminated, though rather plentiful, and the principal associated sulphides are arsenopyrite and pyrite; much of the gold is intimately associated with relatively small amounts of tetrahedrite and galena. In places it is distributed throughout shoots of considerable magnitude; one stope is reliably reported to have produced over $600,000. All the producing mines of the district are on veins of this group.

### MINERALOGY

In the following pages are given brief notes on the occurrence and association of the principal ore and gangue minerals of the ore deposits. Included in the notes are all the more diagnostic minerals of the several types of veins, which though they do not at present seem to present economic possibilities, nevertheless have had a part in the sequence of geologic events leading up to the formation of the commercially important veins. Minerals formed by alteration of the wall rocks are also included because their presence is thought to have diagnostic value in underground exploration. The minerals are described in alphabetic order.

*Ankerite.*—Under the name "ankerite" are described the calcium-magnesium carbonates that contain iron as $CaFe(CO_3)_2$—that is, iron-bearing dolomite. The mineral is widely distributed throughout the district, having been formed by the hydrothermal alteration of the wall rocks and as veinlets traversing these rocks. It is milky white or creamy in color and is generally referred to locally as "spar."

Ankerite has not been observed by the writer as a constituent of the ores. The carbonate that occurs with the vein quartz is predominantly the calcium carbonate, calcite, which is deposited interstitially in the quartz or as minute veinlets cutting the early and late quartz of the fissure-filling and replacement type.

In the veinlets in the wall rock ankerite is generally intergrown with secondary quartz, which destroys its cleavage and gives the material an apparent hardness greater than that of the carbonates, thus rendering it difficult of identification in the field. This material is distinguished from calcite by the fact that it is only slightly attacked by cold dilute hydrochloric acid.

Veinlets of macroscopic dimensions usually have a central core of microcrystalline quartz with the ankerite-quartz intergrowth along the outer walls. Microscopic study of these veinlets leads to the conclusion that the quartz fills the original fracture or circulatory channel and that the ankerite is the result of a metasomatic replacement of the constituent rock minerals. From this conclusion it follows that quartz, probably as colloidal silica, was largely filtered from the solutions by the vein rocks, but the highly carbonated solution penetrated the enclosing rock and formed the carbonates by metasomatic replacement. The deposition of the ankerite apparently occurred during a late phase of the alteration, for it replaces remnants of the original quartz. The distribution of isolated areas of ankerite suggests that it has replaced chlorite and epidote, which are themselves alteration products of the hornblende in the original wall rock. The tiny veinlets of ankerite that cut across the texture of the altered rock indicate that ankerite deposition continued into a late phase of mineralization.

The ankerite occurs only in the country rock associated with the veins formed at intermediate temperatures. It was not noted in the wall rocks enclosing the small quartz lenses, such as those deposited in opened joint planes.

*Arsenopyrite.*—Arsenopyrite occurs sparingly but is widely distributed in the ores and altered wall rock of the district. In the altered wall rock arsenopyrite is subordinate to pyrite, but in the veins the ratio varies greatly in different parts of the district. In the Lucky Shot mine the arsenopyrite constitutes a far greater proportion of the sulphides than it does in the northeastern part of the district. The association of arsenopyrite with gold is common but not universal.

Arsenopyrite occurs as isolated crystals in the vein quartz, as a rule closely associated with pyrite. It was deposited early, before the deposition of the gold and the later vein quartz with which the gold is associated. Microscopic examination of polished surfaces shows that arsenopyrite is replaced by tetrahedrite, galena, and gold.

*Bornite.*—Bornite was noted in the schlieren on the War Baby property, where it appears to be the result of magmatic differentiation. Isolated patches of this mineral reported as occurring in the unaltered "granite" at several localities in the district probably originated in the same way.

The most extensive occurrence of bornite is that opened up on the Holland property in upper Purches Creek, where the mineral, associated with chalcopyrite, replaces feldspars in the pegmatite dike and fills fractures in the later quartz that was introduced after a reopening of the pegmatite. (See fig. 27.) No bornite was noted in the ores from the intermediate-temperature gold veins.

*Calcite.*—Calcite occurs sparingly in the Willow Creek district. It is present in the early coarsely crystalline quartz of the intermediate temperature veins, where it was deposited interstitially. It is also present as a late mineral in the gold ores, deposited in tiny veinlets that cut both the early and late quartz of the veins. In the wall rocks it is the latest mineral, and calcite veinlets cut the ankerite veinlets. In its association with the intermediate-temperature veins and their wall rocks calcite is the latest gangue mineral. Calcite cuts all earlier minerals deposited by hot solutions. It is present in the veins that carry molybdenite and chalcopyrite, and outcrops of these veins exhibit numerous cavities from which the calcite has been leached.

*Chalcopyrite.*—Chalcopyrite is found in the four types of veins within the district and is associated with bornite as an abundant mineral of a pegmatite dike on upper Purches Creek with molybdenite disseminated in the massive quartz of the early veins; very sparingly with sphalerite galena, and gold in the mineralized joint planes; and in small quantities with sphalerite, arsenopyrite, and pyrite of the early period of mineral deposition in the late intermediate-temperature gold veins of the district.

*Chlorite.*—Chlorite is common in the altered wall rocks of the intermediate-temperature veins and gives to these rocks a greenish color. The mineral occurs principally as a metasomatic replacement product of biotite and hornblende and belongs to an early stage of wall-rock alteration. As the action of heated solutions progressed, the chlorite was eventually all replaced by ankerite. Rock in which this occurred presents a distinctly bleached appearance and has lost its resemblance to the original quartz diorite. Chlorite or a similar green micaceous mineral is sparingly associated with the quartz of some of the intermediate-temperature veins. Its distribution suggests that it was derived from incompletely replaced remnants of country rock.

*Dolomite.*—See Ankerite.

*Galena.*—Galena is present in two types of veins in the district. It is disseminated as coarse cubic crystals in the quartz lenses in the joint planes, where it is associated with sphalerite, chalcopyrite, and native gold. In the intermediate-temperature veins, where it is associated with tetrahedrite and gold, it is present as irregular masses rather than as crystals; it has usually replaced the earlier sulphides and appears to have been introduced after pyrite, chalcopyrite, and sphalerite and in association with the fine-gained quartz. In the Lucky Shot mine the presence of galena seems generally indicative of a high gold content, but this criterion is usually of little practical value in the field because of the difficulty of identifying the galena in the minute quantities normally present.

*Gold.*—Gold is the only metal of economic value mined in the district at the present time. Silver occurs with the gold in subordinate amounts. Present economic conditions prohibit exploration of the few copper showings.

All the gold in the veins in the quartz diorite occurs as the native metal and is unusually pure, about 0.950 fine. Gold from the quartz stringers in the mica schist area carries considerably more silver; an average from several assays shows it to be about 0.750 fine.

Notwithstanding the reported occurrence of gold tellurides in the Lucky Shot ore,[19] the present investigation failed to reveal the presence of tellurium in any

[19] Smith, P. S., Mineral industry of Alaska in 1929: U.S. Geol. Survey Bull. 824, p. 18, 1932.

of the Willow Creek gold ores. A qualitative analysis of a rich sample of ore from the Lucky Shot mine, said to be part of a specimen in which tellurides had earlier been identified, was made by Charles Milton in the chemical laboratory of the United States Geological Survey and showed copper, lead, and antimony but no tellurium or boron. This analysis confirms the microscopic identification of tetrahedrite and galena and the absence of a telluride in that particular specimen. Microscopic examination of many polished surfaces of the gold ores has demonstrated the persistent close association of gold with tetrahedrite and galena but has failed to reveal the presence of a telluride in any of the specimens examined. It may be definitely stated that a gold telluride, if present at all, occurs in very minute quantity.

The gold is usually in very fine particles. It occurs as an interstitial filling in the vein quartz and in irregular masses closely associated with tetrahedrite and galena. It has also replaced pyrite, arsenopyrite, sphalerite, and chalcopyrite. Gold was introduced into the veins at a late stage of the mineralization with the late microcrystalline quartz, after a reopening of the veins. It was the last metallic mineral to be deposited from heated solutions.

The general tenor of the ores so far mined in the district is high. The average of all ore mined in the three mines on Craigie Creek—the Gold Bullion, War Baby, and Lucky Shot—was, respectively, $35, $45, and $50 to the ton. A single shoot in one of the Craigie Creek mines is reliably reported to have averaged about 5 feet in width and to have produced between $600,000 and $800.000.

The presence of pyrite and arsenopyrite is not necessarily indicative of the presence of gold in the ores. High gold content does, however, seem to be coincident with the presence of tetrahedrite and galena in the late intermediate-temperature veins, but these minerals usually occur in microscopic amounts and are difficult of identification in the field.

The gold is in general fairly evenly distributed within the area of a shoot, but "specimen ore" is occasionally encountered. Enrichment of gold has played little if any part in the present tenor of the ores. Oxidation is superficial, owing to rapid erosion of the vein outcrops by snow and ice. Gold observed on a slickensided surface in the Gold Cord mine seems to have been rubbed onto the polished surface of the quartz.

In the chalcopyrite-galena-quartz veins occupying joint planes the gold is fairly coarse and irregular in distribution. Some veins yield small quantities of very rich "specimen rock" but do not offer promise of ore on a commercial scale.

*Kaolin.*—A mixture of kaolinite and other aluminum silicates with more or less quartz and other impurities (gouge) occurs along the slickensided walls of the gold quartz veins and forms a great part of the rock in the postmineral fault zones. Decomposition of the feldspars by surface water is doubtless responsible for the formation of the kaolinite in the claylike material. Kaolinite is difficultly distinguishable from sericite in the field, and both minerals are generally referred to as "talc" by the miners.

*Molybdenite.*—The sulphide of molybdenum is associated with chalcopyrite and quartz in a few of the veins. It occurs in platy masses, some of which are as much as several centimeters in diameter. Molybdenite is generally accepted as a high-temperature mineral, so it is believed that the veins containing it are older than the other veins of the district, here classed as intermediate-temperature veins.

*Muscovite.*—The colorless variety of mica, muscovite, is present in the wall rocks as an alteration product of the brown mica, biotite. It is generally abundant where ankerite, pyrite, and arsenopyrite are present. The mineral occurs in the distinctly platy form that serves to distinguish it from sericite, which is also a micaceous mineral of the altered wall rocks and is here and there intermixed with the vein quartz.

*Pyrite.*—Pyrite, the disulphide of iron, is the most abundant metallic mineral in the gold ores. It occurs most commonly in the cube and elongated prismlike forms. It is also almost universally present in the altered wall rocks. Pyrite was among the earliest metallic minerals to form in the veins, where it is associated with arsenopyrite and minor amounts of sphalerite and chalcopyrite. Under the microscope pyrite has been observed to be replaced by gold, tetrahedrite, and galena.

The distribution of pyrite in the altered wall rocks indicates that it is concentrated principally in areas of altered biotite. As the well-formed crystals cut indiscriminately across contiguous minerals of the wall rocks it is clearly a mineral of metasomatic replacement. In the veins the pyrite appears to have crystallized simultaneously with the early quartz.

*Quartz.*—Quartz is the most abundant mineral in the veins of all types throughout the Willow Creek district. In a mineralized pegmatite dike on upper Purches Creek it occurs both as a primary constituent of the pegmatite and as a filling in fractures later than the pegmatite. This later quartz is massive, clear, and glassy. The quartz of the chalcopyrite-molybdenite veins is usually massive and milky white. Where exposed in the outcrops it is more or less discolored by iron stains (limonite).

In the veins of the early intermediate-temperature type which fill joints the quartz usually exhibits comb structure with many drusy cavities and areas of interlocking quartz crystals. Pyrite and galena occur in holocrystalline forms in this quartz, but the chalcopyrite was deposited in irregular masses.

Quartz deposition undoubtedly extended over a longer period in the late intermediate-temperature gold veins than in the other three types of veins. The early quartz of these later veins, which are the most valuable commercially, is massive and glassy to milky white in color. Where undisturbed it exhibits a coarse hypidiomorphic and comb texture and is remarkably free from drusy cavities. Microscopically, this early quartz is seen to contain innumerable inclusions, probably liquid. These tiny inclusions are concentrated in wandering lines which commonly pass from one crystal to the adjoining ones.

The early quartz was deposited as a filling in open fractures and by the metasomatic replacement of included fragments of the wall rock. (See fig. 30.) Opening by movement in the plane of the veins during the early period of quartz deposition is shown by a coarse brecciation of the early white quartz and its cementation with a darker smoky quartz of coarse crystalline texture. Overlapping of broken segments of the white quartz may be seen in many places. (See fig. 28.) Pyrite, arsenopyrite, and minor amounts of sphalerite and chalcopyrite were deposited during the early period of quartz deposition, and the presence of these minerals does not, in itself, indicate the presence of gold in the ore. A small amount of calcite was deposited interstitially with the early quartz.

Shattering of the vein filling occurred again near the end of this period of quartz deposition, and fine-grained (microcrystalline) quartz was deposited in these late fractures (see fig. 29) and as a cementing material in the areas of intense brecciation of the earlier quartz. Much of the earlier quartz has developed typical ribbon texture, which can be detected only by the microscope. Channels for the circulation of late solutions were opened along the contact of the early quartz and the country rock, and the resulting quartz closely resembles chalcedony, but the microscope shows it to have a microcrystalline texture. (See fig. 30.)

The late quartz is colorless to dark gray in the hand specimen. The darker variety owes its color to the inclusion of finely comminuted earlier sulphides and other particles.

Gold was introduced into the later intermediate-temperature veins with the microcrystalline quartz of the last phase of quartz deposition. Tetrahedrite and galena also belong to this late stage of mineralization. They occur where several grains of the late quartz meet. Sericite was also deposited in small amounts with the microcrystalline quartz and gives to some of the ore a distinctly velvety and sometimes slightly greenish appearance.

Quartz occurs only in subordinate quantities as an alteration product in the wall rocks. It is intergrown with sericite and ankerite and is invariably microcrystalline in texture.

*Sericite.*—Sericite, a variety of muscovite, occurs typically in the wall rock and veins of the district as thin films on earlier minerals, as scaly masses, and as intergrowths with secondary quartz. It also occurs sparingly in the gold quartz ore of the late mesothermal veins. The mineral is often called "talc" by miners. In the wall rocks sericite developed later than the chlorite, but its deposition ceased before that of ankerite. In much of the rock it completely replaces the feldspars and to a less extent the primary quartz. It is a late hydrothermal mineral.

*Sphalerite.*—Sphalerite, the sulphide of zinc, occurs very sparingly in the veins of the Willow Creek district. In the late intermediate-temperature veins it is disseminated in the early quartz and commonly contains microscopic blebs of chalcopyrite. It belongs to the early period of metallic sulphide deposition and is sometimes replaced by tetrahedrite, galena, and gold.

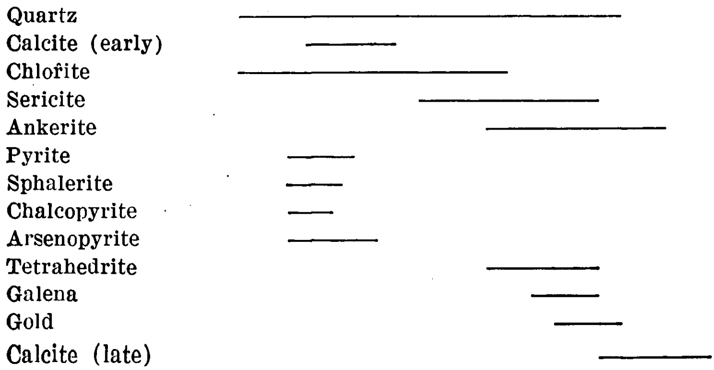
*Tetrahedrite.*—The copper sulphantimonite, tetrahedrite, appears to be intimately associated with the gold in the late intermediate-temperature veins. It usually occurs with galena in irregular masses of microscopic dimensions. A few specimens rich in tetrahedrite were obtained from the Lucky Shot and Mabel mines. The tetrahedrite in these specimens is visible to the naked eye or under the magnifying glass. It is associated with galena and free gold and can be distinguished by its dark iron-gray color and metallic luster. Tetrahedrite occurs as a replacement product of the earlier sulphides and interstitially in quartz.

Chemical analysis of a sample of metallic concentrates from the Lucky Shot mill shows the arsenic content as 15.8 percent and the antimony only 0.15 percent. It is evident, therefore, that antimony-bearing minerals make up only a very small proportion of the total sulphide content of the ore and that most of the antimony may readily be accounted for by the tetrahedrite. Stibnite has previously been reported in the ores of the Willow Creek district, but the foregoing analysis and the relatively small amount of tetrahedrite would seem to indicate that if present it must be in exceedingly small amounts.

*Other minerals.*—Cinnabar has been reliably reported as occurring very sparingly in the superficial ores. It was not observed by the writer, and no information is available as to its distribution or relations to the other minerals. It is possible that, as is common elsewhere, the tetrahedrite may in places carry a small amount of mercury. Superficial weathering of mercurial tetrahedrite might cause the deposition of a small amount of secondary cinnabar.

Limonite, azurite, malachite, and other oxidation products are reported in the ores at shallow depths. Practically all these ores have long since been mined out, and the workings are now caved or otherwise inaccessible for examination.

*Paragenesis of the ore minerals.*—The sequence and relative duration of deposition of the principal minerals by hot solutions in the late intermediate-temperature gold veins in the Willow Creek district are indicated below:




#### STRUCTURAL FEATURES

As yet no field observations are available by which these small quartz lenses may be correlated structurally with the late gold quartz veins in which the large ore bodies were deposited. Jointing had been developed in the quartz diorite before either the lenses or the veins were formed. The quartz lenses are confined within the walls of the joint planes. The veins, though in places they conform with the strike and dip of the joint planes, usually cut across them at acute angles. The fractures along which the veins are formed were obviously brought about by forces that were later, of a different nature, applied in different directions, and more deep seated in origin than the forces that developed the jointing.

Underground development in the Lucky Shot and Fern mines has demonstrated the branching character of the fractures in which the veins were formed. The vein fractures are seldom clear-cut breaks but rather are combinations of roughly parallel breaks that resulted in the formation of numerous mineralized stringers, some of which cut into the country rock. Many of the fractures have broken along parallel planes in such a way as to include flat tabular "horses", locally called "vein fill", of considerable lateral extent. In such places there are generally a hanging-wall stringer and a footwall stringer of quartz, which are separated by altered country rock (vein fill) as much as 8 or 10 feet thick. The quartz stringers range in thickness from a few inches to several feet. Postmineral movement has generally formed slickensided walls which may include both footwall and hanging-wall quartz or may exclude one or the other. Mining operations have generally been confined to following between the slickensided walls and in places undoubtedly have passed by valuable portions of gold quartz which have been isolated outside of the slickensided walls by postmineral movement. Only a minor amount of crosscutting has been done in the mines of the district, and the writer believes that in many places the full width of the mineralized zones has not been determined.

Where quartz 2 feet or more thick has been deposited there is generally evidence of movement during the period of quartz deposition. Movement between the vein walls has produced at some places lenses of considerable lateral extent and as much as 14 feet thick. The largest lens that has been exploited has produced ore that averaged over $50 to the ton and yielded a total of over $600,000. The postmineral movement in the plane of the vein has probably contributed somewhat to the thickness of these lenses by sliding one portion

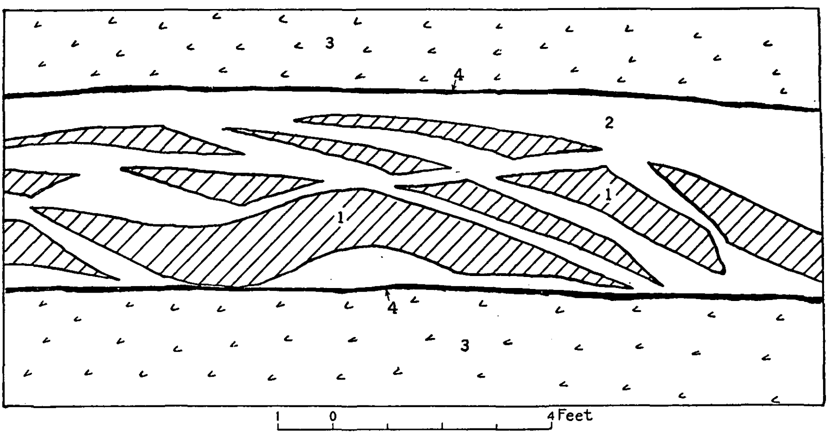



FIGURE 28.—Section of vein in Lucky Shot mine, 350-foot level. 1, Early coarsely crystalline quartz; 2, late quartz matrix; 3, country rock; 4, slickensides.

down over another, as may be observed by slickensided surfaces within the main body of the quartz lenses and by the overlapping of broken bodies of quartz.

Quartz breccia cemented by quartz is evidence of movement within the veins during the period of quartz deposition. At many places it is possible to observe an earlier milky-white quartz that has been crushed and cemented by a later dark quartz. (See fig. 28.)

The veins present many types of texture, each of which is associated rather definitely with the structure of the fractures in which the vein quartz occurs.

Coarsely crystalline comb quartz, though not the most common, is nevertheless thought to represent the typical primary structure of the veins. It is observed in the parts of the veins that have been subjected to the least amount of reopening during and since quartz deposition. At such localities the veins consist of a series of roughly parallel quartz stringers ranging in width from a fraction of an inch to a foot. The width of the mineralized zone as observed may be from 2 to 6 feet, and the principal stringers are connected by numerous cross veins. Where this structure is in evidence the slickensided walls are generally less well developed or lacking. Figure 29 illustrates branching quartz stringers of this type. Quartz in a hand specimen from the point illustrated in figure 29, in the 500-foot level of the Lucky Shot mine, has a glassy, banded appearance, somewhat discolored by greenish chlorite. As seen under the microscope, in thin section, the comb texture is apparent, although some specimens exhibit hypidiomorphic forms of the quartz; the gold is associated

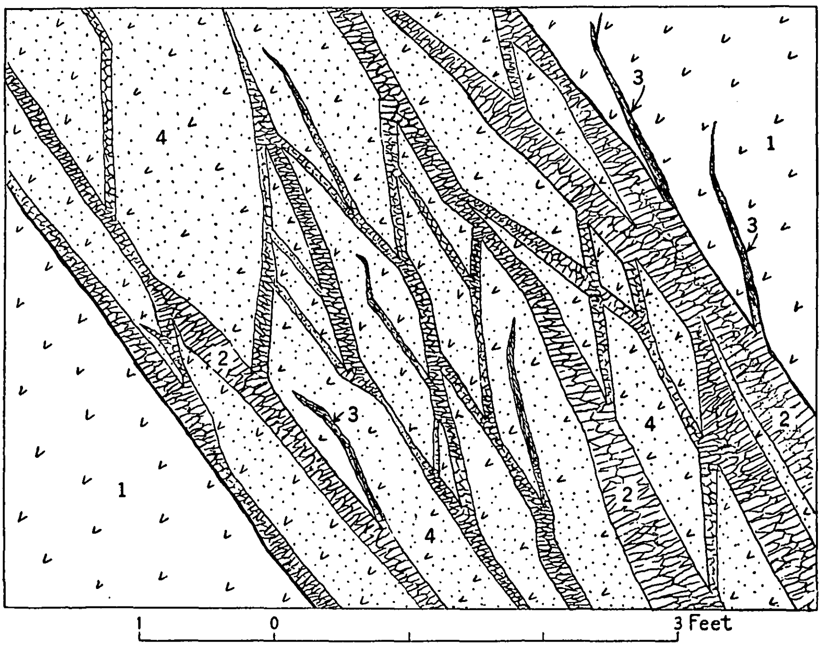



FIGURE 29.—Section of vein in Lucky Shot mine, 500-foot level, showing footwall stringer near southwestern fault. 1, Fresh country rock; 2, quartz veinlets showing comb structure; 3, microcrystalline quartz and carbonates; 4, altered quartz diorite "vein fill."

with fine-grained quartz, which occupies tiny fractures cutting indiscriminately across the texture of the earlier quartz; and carbonate-filled fractures cut across quartz of both ages. Crustification and drusy texture are absent from all ores studied.

Quartz replacement of fragments of country rock is common. The partly replaced fragments of quartz diorite occur more or less unsupported in a matrix of early quartz, and their borders merge gradually into the quartz matrix. Viewed microscopically the remnants of these fragments are seen to be highly altered. In most samples the plagioclases and biotite are completely replaced by quartz, sericite, and carbonates. Though to the naked eye these rock fragments present the texture and appearance of a bleached granitic rock, they actually have been subjected to complete metasomatic replacement by the vein minerals. Microgranular quartz veinlets cutting the rock fragments also are numerous. Here, also, pyrite and arsenopyrite are more abundant than in the quartz of the open-space filling.

Massive milky quartz commonly occurs as tabular vein filling associated with dark-gray quartz. Both varieties exhibit banded or ribbon structure which has been developed by crushing during the period of quartz deposition and later. Studied microscopically, the darker quartz shows greater crushing and cementation by micro-

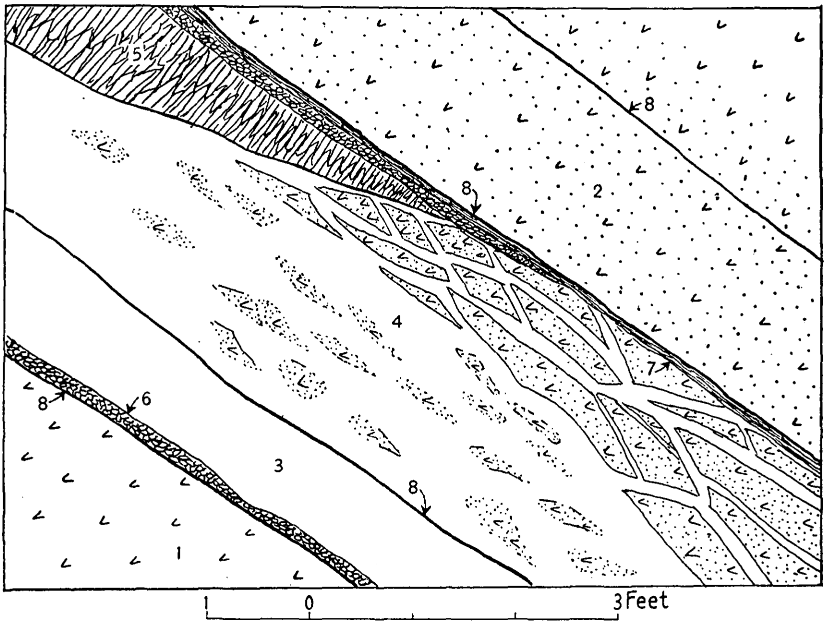



FIGURE 30.—Section of vein in Lucky Shot mine, raise 553, 75 feet above 500-foot level. 1, Slightly altered quartz diorite; 2, highly altered quartz diorite; 3, light-colored dense, massive quartz; 4, dark quartz that has replaced quartz diorite; 5, colorless quartz exhibiting comb texture; 6, microgranular quartz; 7, gouge on slickensided wall; 8, slickensides.

crystalline quartz, and some of it contains many particles of early sulphides. Figure 30 illustrates the occurrence of vein filling of this type, which replaced the shattered quartz diorite. Thin sections of both the dark and light colored quartz show its primary texture to be hypidiomorphic.

Lindgren [20] considered this type of quartz characteristic of deposition at intermediate depths and intermediate temperatures. He estimates that it was deposited at depths of 4,000 to 12,000 feet below the original surface.

[20] Lindgren, Waldemar, Mineral deposits, 3d ed., p. 598, 1928.

Banding in the gold quartz of the Willow Creek district is due not only to reopening during the period of quartz deposition, but also to the distribution of the sulphides pyrite and arsenopyrite and minute fragments of wall-rock minerals. Ribbon structure is also common and is produced by fracturing of the hypidiomorphic quartz and cementation by the later microcrystalline quartz. The textures observed are persistently those produced at intermediate depths and the wall-rock fragments included show metasomatic replacement rather than incrustation by vein minerals.

Sheeting is entirely superficial and more or less parallel to flat-lying surfaces of the exposed rock mass. It commonly corresponds with and emphasizes a flat-lying joint plane. Sheeting has no bearing on the economic problem except as, in conjunction with jointing, it accelerates disintegration of the precipitous ridges and mountain masses by the action of snow and ice; the resulting talus conceals vein outcrops and adds to the expense of driving adits on the lower slopes of the valley walls.

Postmineral faulting has cut the rocks of the district into numerous fault blocks, and differential movement between the blocks has caused offsets between contiguous vein segments as well as changes in strike and dip. The offset at some places is as much as several hundred feet, and the conditions are so complex that prospecting has as yet failed to reveal the position of the faulted vein segments. For this reason certain parts of the district that might be expected to contain productive veins are not yet developed. It seems probable, however, that detailed mapping of these structural features will lead to the discovery of faulted portions of known veins or other veins of equal value within the mineralized zones.

### WALL-ROCK ALTERATION

As the younger intermediate-temperature veins are the only ones in which ore appears to have been developed in commercial quantities, especially detailed study was made of alteration in the wall rock of these veins. Wall-rock alteration has not extended beyond the limits of the shear zones within which veins of this type occur. Specifically, the alteration was confined to the country rock lying between the quartz-filled parallel fractures that make up the veins, and it seldom penetrated far beyond the outer limiting walls of such vein series. In the vein zones the amount of alteration and the distance to which it penetrated the wall rocks outside the vein walls vary between wide limits. This variation may be attributed both to the amount of early shattering in the rocks bounding the main fractures, which facilitated or restricted circulation of the solutions, and to the potency of those solutions.

The natural black and white speckled appearance of the unaltered country rock changes with the degree of alteration. Where the rock is green much chlorite is present, but as chlorite is replaced by sericite, secondary quartz, and ankerite the rock assumes an increasingly bleached appearance.

Early stages of alteration were characterized by the replacement of hornblende by chlorite and the alteration of biotite to chlorite and muscovite. Some titanite was developed at this stage as an accessory mineral. Pyrite deposition appears to have been concentrated in areas occupied by biotite crystals. Where the alteration ceased at the early stage the original quartz diorite is now a rock composed principally of chlorite, residual primary quartz, muscovite, and remnants of the original biotite and plagioclase. Pyrite is an accessory secondary mineral.

Intermediate stages are marked progressively by the development of chlorite, secondary quartz, and sericite. More intense alteration resulted in the disappearance of the chlorite, the gradual replacement of the plagioclases by feltlike masses of sericite and secondary quartz, the deposition of isolated areas of microcrystalline secondary quartz, and finally metasomatic replacements of all earlier minerals by the carbonates, principally ankerite. In some places minute calcite veinlets cut indiscriminately through the earlier alteration minerals. In a specimen from the Lucky Shot mine, above the southwest face of the 200-foot level, the only original rock mineral remaining is primary quartz. The plagioclases have completely disappeared, primary biotite has been altered to muscovite, and pyrite and arsenopyrite appear concentrated in and around the muscovite. Ankerite occurs in isolated masses throughout the rock and as tiny veinlets that cut indiscriminately through the sericitic groundmass.

Little information is available regarding wall-rock alteration in association with the supposed higher-temperature veins, as no detailed examination has been made of them below the immediate surface and below the influence of purely surface alteration. At the outcrop of the copper sulphide-bearing pegmatite dike on upper Purches Creek the quartz diorite walls are fresh and unaltered. The feldspars of the pegmatite itself are considerably kaolinized as a result of surface weathering.

Narrow veins of the chalcopyrite-molybdenite type on upper Craigie Creek are bounded by fresh, unaltered quartz diorite. At an outcrop near the Styles property, on the Little Susitna River, the wall rocks were hidden by surface debris. In the galena-chalcopyrite-gold quartz of the mineralized joint planes the development of chlorite is shown by the greenish color of thin slabs of included country rock, but little mining has been done on this type of vein.

Along many of the faults there are zones 20 to probably 100 feet in width within which the rock is so intensely crushed that the crystalline structure of the quartz diorite is completely destroyed, and the original minerals are ground up and altered beyond recognition. This alteration, however, is not due to hydrothermal action but rather to attrition and to the action of ground water on the plagioclase, resulting in the formation of kaolin. These fault zones, where pierced by mine workings, generally carry considerable water. On exposure to air the rock swells rapidly, thus making it difficult to maintain mine openings.

### GENESIS

The ore deposits of the Willow Creek district were formed along fractures in a quartz diorite intrusive mass of considerable size, probably batholithic in character. The gold quartz veins, which have been commercially profitable, were the last of four types of mineral deposits in the region, which exhibit a tendency of deposition from copper to gold.

Gold in significant quantities first made its appearance in the pyrite-chalcopyrite-galena quartz lenses, which formed along joint planes in the quartz diorite. There was little alteration of the wall rock and only sporadic deposition of quartz in this earlier type of deposit. There is no evidence of reopening in these quartz lenses in the relatively short period during which the solutions were in circulation, as the medium to coarse grained comb structure of the quartz is undisturbed.

The ore and gangue minerals of the gold quartz veins are characteristic of the intermediate-temperature type of ore deposit and bear many resemblances to those of the gold quartz veins of the Mother Lode and Grass Valley regions in California, as described by Knopf, Lindgren, and other writers.[21]

In the Willow Creek district gold occurs associated with pyrite, arsenopyrite, sphalerite, chalcopyrite, tetrahedrite, and galena in a gangue of quartz. Ankerite is abundantly developed as a wall-rock alteration product and in the country rock included between the vein walls. The gold has replaced the quartz where several grains meet, or it has replaced the sulphide minerals—pyrite, arsenopyrite, sphalerite, chalcopyrite, tetrahedrite, and galena. It was the latest

[21] Knopf, Adolph, The Mother Lode system of California: U.S. Geol. Survey Prof. Paper 157, p. 37, 1921. Lindgren, Waldemar, U.S. Geol. Survey Geol. Atlas, Nevada City folio (No. 29), 1896; The gold quartz veins of Nevada City and Grass Valley districts, Calif.: U.S. Geol. Survey Seventeenth Ann. Rept., pt. 2, pp. 1–262, 1896. Howe, Ernest, The gold ores of Grass Valley, Calif. (with discussion by A. M. Bateman, Waldemar Lindgren, J. E. Spurr, and the author): Econ. Geology, vol. 19, no. 7, pp. 595–622, 1924. Knaebel, J. B., The veins and crossings of the Grass Valley district, Calif.: Econ. Geology, vol. 26, no. 4, pp. 375–398, 1931. Loofbourow, R. L., The economic geology of No. 2 vein, North Star mine, Grass Valley, Calif. (Stanford University thesis), 1931.

metallic mineral to be deposited and is without doubt closely associated in time of deposition with tetrahedrite and galena, both of which occur in the late quartz and replace the earlier sulphides—pyrite, arsenopyrite, sphalerite, and chalcopyrite.

The intermediate-temperature gold quartz veins of Grass Valley, Calif., according to W. D. Johnston, Jr., are roughly parallel with the margins of a small granodiorite batholith intruded into sedimentary and basic igneous rocks. Pyrite is the principal metallic mineral, and with it are minor amounts of galena, sphalerite, arsenopyrite, chalcopyrite, scheelite, and tetrahedrite. Quartz, ankerite, and calcite are the principal gangue minerals. The quartz is in part idiomorphic, in part sheared and recrystallized as a result of repeated opening of the vein fractures. Comb structure is common, and vugs occur on the lower levels of the mines, 3,700 feet below the present surface. Gold fills fractures in the broken pyrite, has replaced some of it, and occurs in sheared and recrystallized quartz. There is no good evidence of replacement of the wall rock by quartz; rather the vein material appears to occur entirely as a fissure filling.

The main veins, as revealed by mine workings, are persistent both along the dip and the strike. The North Star vein has been followed 6,000 feet down the dip and 4,000 feet along the strike. In the lower levels of the mine a vein system conjugate to the North Star vein has been worked to the 9,000-foot level, 3,700 feet vertically below the surface. The Empire vein has been explored 7,000 feet on the dip and more than 8,000 feet along the strike. The size of the ore shoots is extremely variable. There are many small shoots a few hundred feet in length and a number of larger shoots, notably one 2,400 feet long in the Empire mine and one 2,000 feet long in the North Star mine. The average value of the ore mined in the district is $11 to the ton.

### DEPTH

In the Willow Creek district the greatest depth to which the veins have been opened is approximately 800 feet below the outcrop, in the Lucky Shot mine, on lower Craigie Creek. The next deepest development is in the Fern mine, on upper Archangel Creek, where a depth of 500 feet below the outcrop has been reached. In each mine the lowest openings pierce the ridges several hundred feet above the valley floor. This vertical range can in no sense be interpreted as indicating the depth to which ore deposition has taken place. The shallow depth to which the mines have been opened is the result of operating methods, inadequate financing, and local physical conditions that have no bearing on the persistence of the ores.

The Willow Creek veins seem clearly to belong to the type in which ore deposition has taken place from 4,000 to 12,000 feet below the surface as it existed at the time of their formation. In the California deposits of similar type the veins have been exploited to depths believed to be at least 7,000 feet below the surface at the time of deposition, and they show no appreciable change in the character of their mineralization or gold content. Several mines in California have attained depths of 5,000 feet and more below the present surface. These mines encountered at irregular intervals barren zones, some of which had a vertical extent of as much as 800 feet, yet ore shoots were developed at greater depths below these barren zones. At Grass Valley the veins locally pinch and swell, as they do in the Willow Creek district. In the slight vertical development in the Willow Creek district there is no change apparent in the character of mineralization. Pinching of the veins in some places is due to postmineral faulting but in other places it is only apparent, and further exploration would doubtless show that the veins continue. As the solutions came from below, there must necessarily have been continuous channels for them to flow through in their ascent toward the surface. That there should be any great change in the structural conditions of these channels for a considerable depth does not appear likely, because the fissures occur in an essentially homogeneous crystalline mass, the quartz diorite intrusive.

It is estimated that in the California area there has been not much more than 2,000 feet of erosion since the formation of the veins. There probably has been not much more than this in the Talkeetna Mountain area since the formation of the veins of the Willow Creek district. Structural and mineralogic conditions would therefore seem to support the belief that these veins should be productive to a minimum depth of not less than 2,500 to 3,000 feet below the present surface.

Because the gold occurs in shoots and lenses that are isolated between stretches of rock of low tenor or in veins or lodes that actually pinch out, successful mining must include systematic exploration carried ahead of stoping operations; otherwise the exhaustion of an ore shoot will lead to discouragement and possible closing down of a valuable property. The geologic conditions in the Willow Creek district warrant exploration and offer promise of profitable returns, but the greatest caution should be observed in such exploration to crosscut thoroughly the potential area and study carefully the effect of such slip faulting as may have taken place in the plane of the veins. Exploration should be preceded by an intensive survey of the faulting, and development in the early stages should be confined to following the ore closely and to sink and drift on such vein segments as appear to be long enough to justify development if the search proves successful.

### MINING PROPERTIES

The most productive mines in the Willow Creek district have been the mines on Craigie Creek, especially the Gold Bullion, War Baby, and Lucky Shot, all owned by the Willow Creek Mines, Ltd. In 1931 the Gold Bullion and the War Baby were inactive.

#### LUCKY SHOT

The Lucky Shot mine is 1½ miles northwest of the junction of Craigie Creek and Willow Creek, on the south slope of the ridge that lies between Craigie and Peters Creeks. The claims on which the mine is located were staked in 1918. During the summer of 1920 exploration of the veins was under way by W. S. Horning, C. A. Bartholf, David Miller, and W. T. Rock. In 1921 the property was taken over by its present owners, the Willow Creek Mines. The property consists of 15 patented claims, part of which originally belonged to the War Baby group. (See pl. 13.)

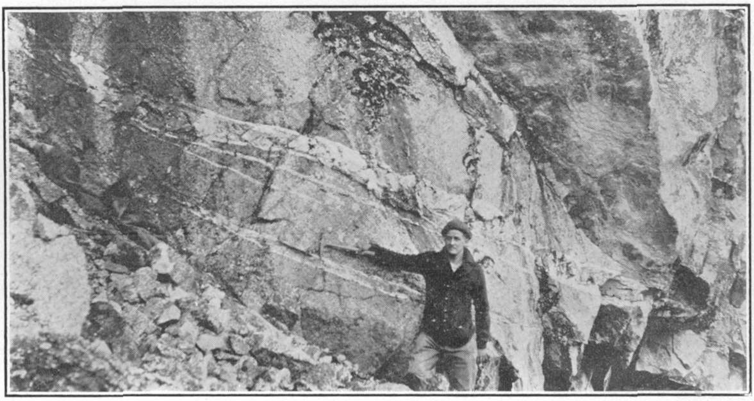
The mine has been a steady producer since 1923, except that in 1924 and again in 1928 fire destroyed the reduction plant and temporarily put a stop to milling operations.

##### SURFACE PLANT

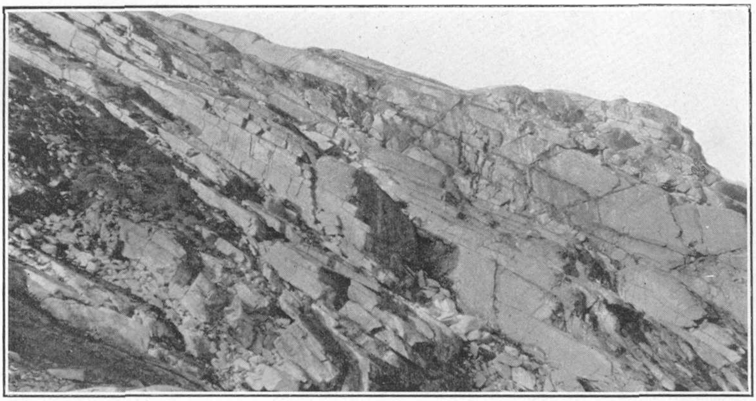
The surface plant at the Lucky Shot mine consists of an up-to-date mill and power plant, assay office, gold-melting room, machine and blacksmith shops, storerooms, and three modern bunk houses with dining room and kitchen facilities to accommodate 100 men; also a number of smaller buildings used for offices and auxiliary housing. (See pl. 12, *C*.)

The mill building, assay shop, and bunk houses are heated by circulating hot water from the cooling system of the power plant. The camp buildings are lighted by electricity. The mill is run by electricity, the generator being operated by a 125-horsepower marine Diesel engine. Compressed air is delivered to the mine by a 75-horsepower combination upright Diesel compressor. About 25 horsepower is generated by water. All power machinery is housed in the lower part of the mill building. Fire protection for the camp is furnished by a water tank on the valley slope above the camp and by numerous extinguishers.

The mine buildings proper consist of housed-in portals at each of the two haulage levels—the upper or 200-foot level and the lower or 500-foot level. The housing also includes ore bunkers and blacksmith shops. At the upper level there is also a bunk house with



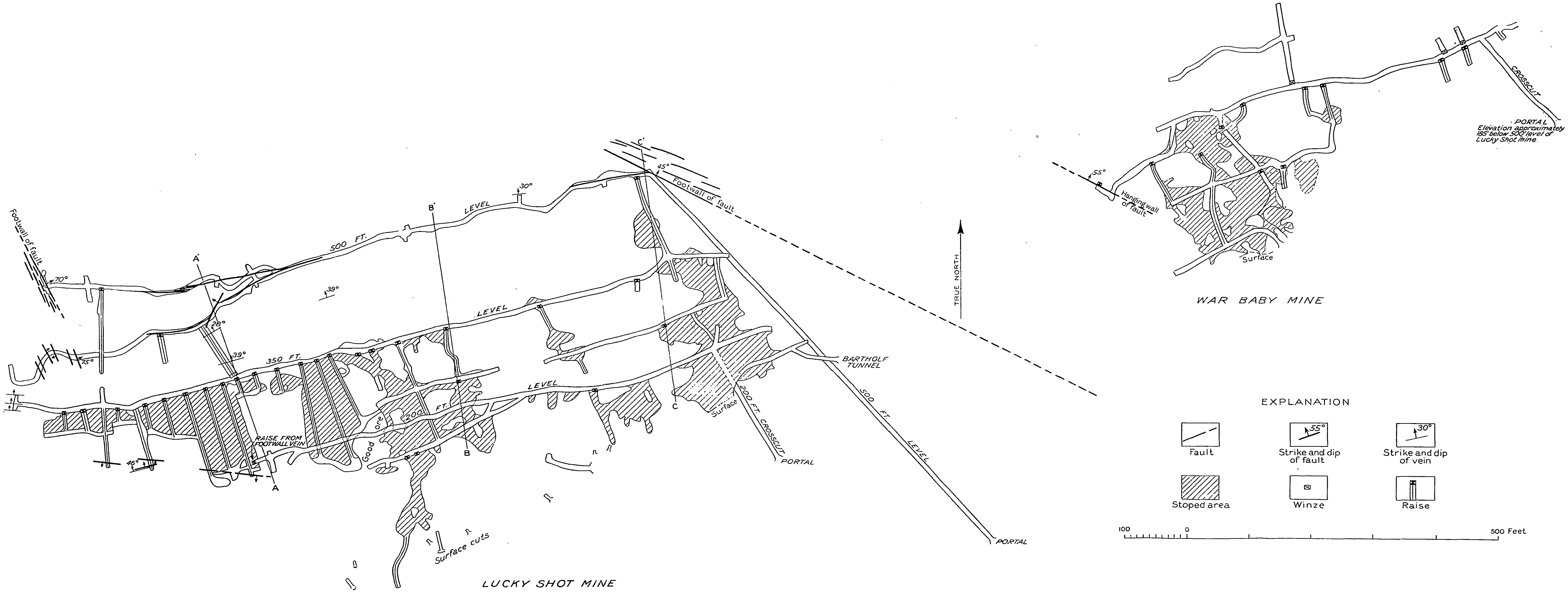
*A*. CHALCOPYRITE-MOLYBDENITE STRINGER IN NORMAL QUARTZ DIORITE AT HEAD OF CRAIGIE CREEK.



*B*. RHOMBIC BLOCKS PRODUCED BY JOINTING IN QUARTZ DIORITE ON PURCHES CREEK.

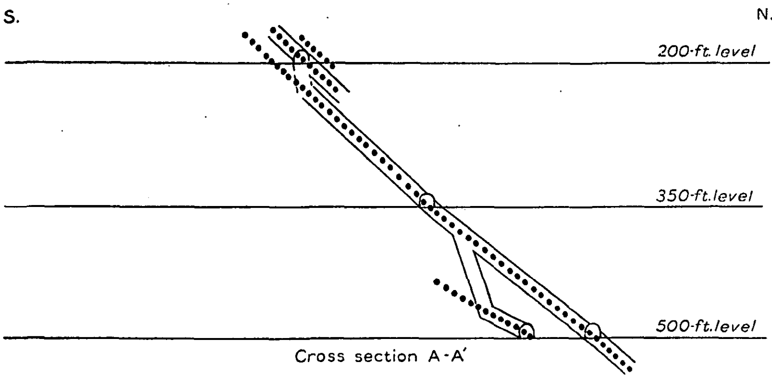
*C*. LUCKY SHOT MINE AND CAMP AND WAR BABY MINE.

Willow Creek mine is in center background. Dump of War Baby mine is in right background.

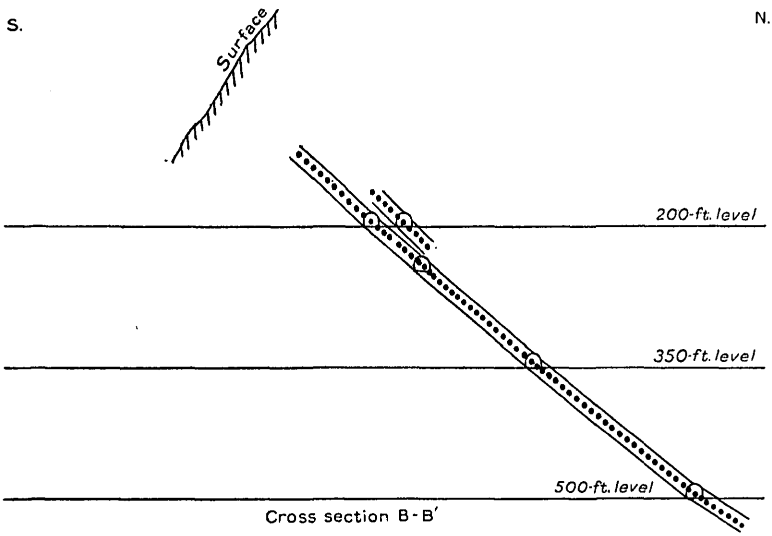



UNDERGROUND WORKINGS AT LUCKY SHOT AND WAR BABY MINES.

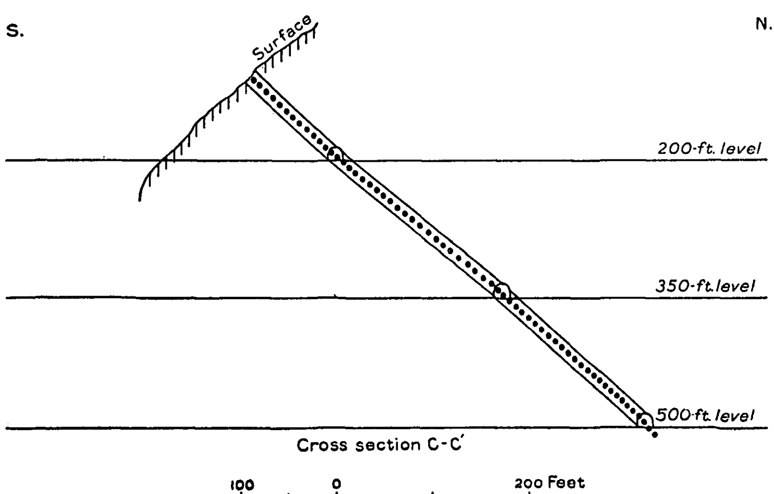
For sections along lines *A-A′, B-B′, C-C′*, see plate 14.




Cross section A-A′




Cross section B-B′




Cross section C-C′



**CROSS SECTIONS OF LUCKY SHOT MINE.**

**See plate 13 for positions of cross sections.**

kitchen facilities to care for 20 men. During the summer all camp and mine supplies are brought in from the railroad at Wasilla by truck and tractor, a distance of 25 miles. In winter supplies are hauled by tractor from Willow, on the Alaska Railroad. It was expected that by the summer of 1932 the winter road would be improved to permit its use in summer also.

The ore bunkers at each haulage level are connected with the mill by a double reversible aerial tramway. The buckets have a capacity of about 800 pounds. The tramway to the lower level is a single span 1,950 feet in length, and its upper terminal is approximately 530 feet higher than the dumping floor at the mill. The tramway to the bunkers at the upper level, also a single span, is 2,250 feet in length and runs to a height of 825 feet above the mill. All supplies are delivered to the mine by means of these tramways. The company operates a sawmill on Willow Creek about 6 miles below the mine, from which it obtains timbers and rough lumber.

### MINE DEVELOPMENT

Early development of the property consisted of numerous open cuts and short tunnels to define the position and extent of the lode and the Bartholf tunnel, which penetrated the top of the largest ore shoot yet developed in the mine. This tunnel was too shallow, however, to provide stoping space and was abandoned. The mine is now developed through two main haulage levels connected with the surface by adits. The upper or 200-foot level is about 850 feet above the camp. The lower or 500-foot level is about 410 feet below the 200-foot level on the dip of the vein and 270 feet lower in elevation. The 200-foot level crosscut enters the vein at a distance of 205 feet from the portal. The 500-foot adit is 825 feet long and pierces the vein where it is cut off by a fault that has displaced the vein several hundred feet to the east, to be again identified in the workings of the War Baby mine. Drifts on the vein on the 200-foot level amount to about 1,200 feet; on the 500-foot level to about 1,600 feet. An intermediate level, the 350-foot level, has no crosscut to the surface, but on it about 1,200 feet of drifts along the vein have been opened. Many raises were driven in the course of development and stoping operations, and their locations are shown on the mine map (pl. 13), which has been furnished through the kindness of Mr. W. E. Dunkle, general manager of the Willow Creek mines. All workings are terminated on the east by a fault zone that has a general northwest strike and a dip to the northeast. A similar parallel fault is pierced by the west end of the 500-foot drift but has not yet been encountered in the workings above this level. The ground in these fault zones is very heavy, and no attempt has yet been made to drive through it. The present mine workings are confined within a block approximately 1,200 feet in width between two northeastward-dipping fault zones. Other small faults have as yet caused no serious difficulties in mining.

Little timber is necessary in the main drifts, as the ground stands well. Stopes are worked by the overhand method and back-filled with waste. An average stoping width is 4 to 6 feet, although much greater widths are necessary where thick quartz lenses are mined.

### MILLING PRACTICE

The new mill, put into operation early in 1931, is a thoroughly modern plant with a daily capacity of 35 tons. The management had in contemplation plans to increase the capacity to 50 tons by enlarging the ball mill. The mill feed averages about $50 a ton.

The accompanying flow sheet (fig. 31) shows graphically the general course of treatment of the ore and was furnished by Mr. L. J. Till, mill superintendent. Mr. Till was mainly responsible for the general plan, which was worked out in collaboration with A. J. Wenig, of the Colorado School of Mines.

The salient features of the ore treatment are concentration of the sulphides and their amalgamation and cyanidation for the recovery of the gold. Concentration is accomplished on a Gibson table and a 4-cell mineral separation flotation machine. Siliceous tailings from the flotation machine are discarded without further treatment. About 85 percent of the gold is obtained in the top cut on the Gibson table. The top-cut concentrates are collected in buckets, and the gold is amalgamated once a day in a batea. The second cut from the table goes to an amalgamating pan, which is in closed circuit with a small Hardinge mill and Akins classifier. The sulphide tailings from the batea are added to this closed circuit. Siliceous material or tailings from the Gibson table are returned to a Dorr classifier and again go through the ball-mill circuit. Overflow from the classifier passes to the flotation machine. Sulphides from the flotation machine are added to the table concentrates in the pan-amalgamation circuit. All tailings from pan amalgamation are cyanided in Devereaux agitators. The sulphides after cyanidation run about $40 in gold and are stored for shipment. The flotation tailings run from 90 cents to $2 a ton. The ratio of concentration is about 68 to 1.

### GEOLOGY

The country rock at the Lucky Shot mine is the normal quartz diorite of the region. At the surface this rock is jointed and sheeted, but this structure is not well developed underground. Mine openings approach the vein or mineralized lode from the footwall side, and the country rock is very fresh and unaltered up to the footwall

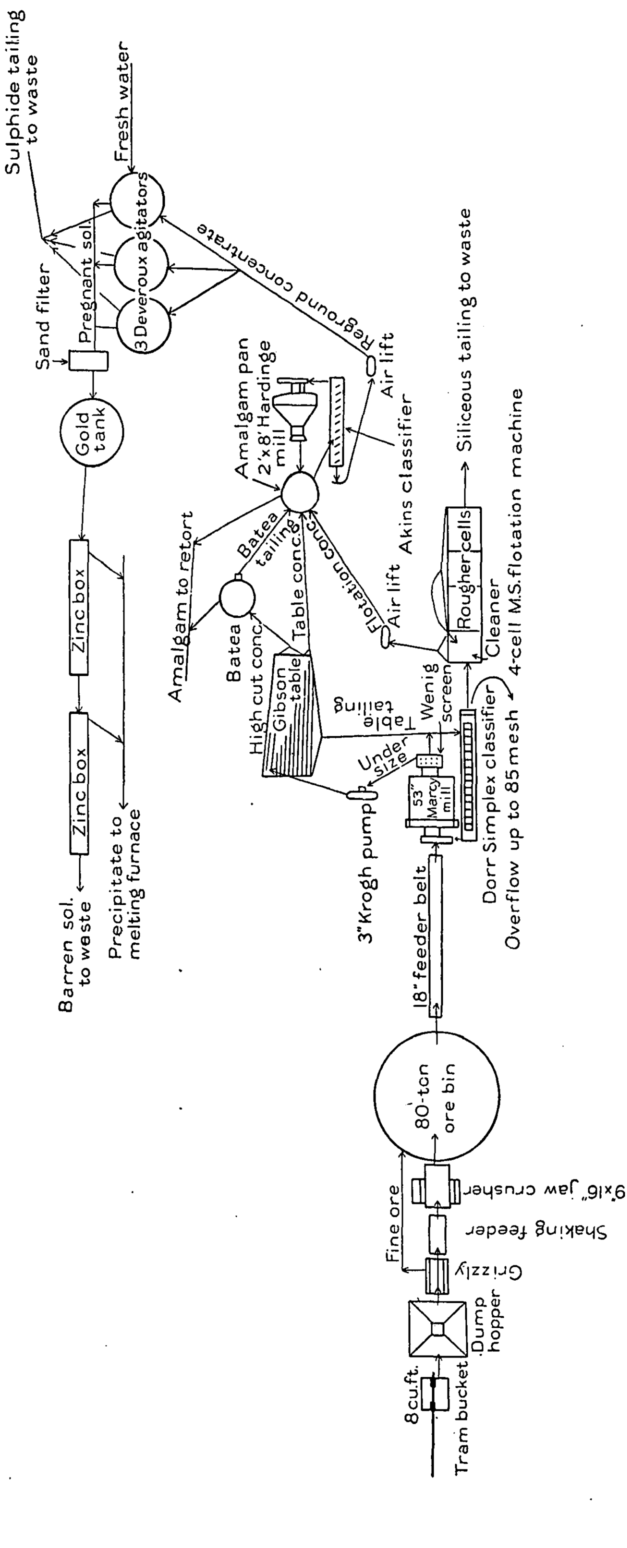



FIGURE 31.—Flow sheet of Lucky Shot mine.

slickensides. The vein system has a general strike of N. 80° E. and an average dip of 40° N. It has been developed to a maximum depth of about 800 feet below the outcrop in the western part of the mine and has been opened continuously from the 500-foot level to the surface in the eastern part. (See pls. 13, 14.)

The main fissure, as exposed in the eastern workings, appears to define the footwall of a mineralized zone whose thickness has not yet been determined by crosscutting. To the west the vein branches, as shown on the 500-foot and 200-foot levels, but development to date indicates that the north branch on the 500-foot level corresponds to the south branch as exposed on the 200-foot level. No branching of the vein has been disclosed by the drift on the 350-foot level. It seems probable, therefore, that a crosscut to the north in the western part of the mine should encounter a vein that forms the north branch on the 200-foot level. The south branch on the 500-foot level has a flat dip (29°) in its eastern part but steepens considerably toward the west as it gains distance from the main or footwall vein. In an area shattered by small transverse faults the quartz carries some very high percentages of gold.

Mine development indicates that the vein may be a single mineralized fissure in the eastern part of the mine and that it branches, fingerlike, along its strike to the west. On the other hand, a short crosscut into the hanging wall 190 feet west of raise 551, on the 500-foot level, shows several quartz stringers in highly altered country rock. These stringers dip 30° N., though the dip of the main vein is about 40°. It is apparent, therefore, that the hanging wall of the mineralized zone has not been definitely determined, so the possibility that another gold-bearing stringer may be encountered cannot be dismissed until the entire width of the altered zone has been crosscut.

Raises and stopes above the 350-foot level have shown that the vein on this level is the same as the one on which stoping has been carried up from the south branch on the 200-foot level. It is the vein that has provided nearly all the ore from the western half of the mine. The continuity of this vein has been established in the eastern part of the mine by raise 551 from the 500-foot level to the 350-foot level, and thence to the surface by stopes and raises. Because of low gold content along the 500-foot drift no raise had been put up west of raise 551 until 1931, when raise 556 was put up to connect the western 350-foot level with the 500-foot haulageway. It started up on the south drift of the 500-foot level, on a flat vein (29° dip) known as "the footwall stringer", but the inclination of the raise was increased to intersect the steeper vein exposed on the 350-foot level and make the raise available as an ore chute for stoping operations above. Thus the main vein was not explored above the north drift on the 500-foot level in the western workings, except for a short distance below the 350-foot drift.

Until recently it was supposed that the vein exposed in the north drift on the 200-foot level carried only ore low in gold. In cleaning out this drift the hanging wall was barred down, and behind slabs of altered country rock thus exposed was a quartz stringer 2 to 6 inches in width carrying over $200 in gold to the ton.

*Distribution of quartz.*—The vein quartz assumes the greatest thickness in the eastern part of the mine. It is normally 2 to 4 feet thick, but in the Hogan stope, the largest shoot of ore mined in the district, it averaged 6 feet and was much thicker in some of the lenses. Toward the west the quartz mineralization tended to develop a network of stringers from 1 inch to 1 foot thick, separated by highly altered rock. In places the vein is composed of "footwall" and "hanging wall" quartz stringers, which are divided by 2 to 5 feet of altered rock. The total width of these zones of quartz is in few places fully shown by the mine workings, owing to the absence of much crosscutting beyond the postmineral slickensided walls between which the drifts and raises are driven.

Where quartz occurs in what appear to be the major fractures it usually is banded and much of it shows evidence of crumpling and recementing during the period of deposition of later quartz. The quartz was deposited both in fissures and as a filling in open spaces.

Abnormal width of quartz in the lenses appears to be due in part to repeated openings during quartz deposition combined with movement in the plane of the earlier fractures, which not only caused a brecciation and telescoping of the quartz already deposited but also formed new lenses or enlarged earlier ones. The early massive quartz exhibits both hypidiomorphic and comb texture. Where enough gold is present to form ore the massive quartz is shattered and recemented with a fine-grained quartz that is in large part microcrystalline and difficult to detect except under the microscope.

*Wall-rock alteration.*—Wall-rock alteration along the veins consisted of chloritization, sericitization, and ankeritization. In the Lucky Shot mine the wall-rock alteration was intense within the zone of shattering along the veins. There is little evidence of hydrothermal alteration below the footwall of the vein where it is pierced by the adits on the 200-foot and 500-foot levels. The total distance to the actual hanging wall of the mineralized zone has not been crosscut, but the rocks show that alteration continued beyond the hanging walls of the veins as opened by the mine workings. The alteration was undoubtedly accomplished by heated solutions of deep-seated origin that must have continued in circulation for a long time. Ankerite stringers occur in the wall rocks accompanied by secondary quartz, but ankerite was not observed in association with the vein quartz. Ankerite is particularly abundant in the " vein fill ", which occurs as a tabular horse or sheetlike mass between footwall and hanging-wall quartz stringers. Intense ankeritization and sericitization have occurred side by side and given the rock a distinctly bleached appearance. Chloritization has given the rock a greenish color. All three types of alteration were accompanied by the formation of pyrite and at some places arsenopyrite close to quartz stringers and veins.

*Distribution of gold.*—Gold is distributed in the lode of the Lucky Shot mine in well-defined shoots in the quartz veins. It has not yet been found in the country rock. Mining has pretty well determined the extent of the shoot in the eastern part of the mine, the Hogan stope, but has not yet developed the boundaries of the shoot in the western part. The Hogan stope seems to indicate that the long dimension of this ore shoot lies with the dip of the vein, but in the western part of the mine the long dimension of the shoot is apparently along the strike of the vein. In the western part stoping of the ore shoot has been carried down to the 350-foot drift, and assays of samples along this drift indicate that good ore extends to an unknown depth below the 350-foot level. The mine map (pl. 13) and cross sections (pl. 14) show that ore has been developed for a distance of about 500 feet from the surface down the dip of the vein. In the south drift on the 500-foot level high-grade ore has been found approximately 700 feet down the dip in the extreme western part of the workings; the further continuation of this ore in depth can be proved only by actual development, but conditions appear to indicate such continuation. The similarity of the Lucky Shot veins to those in the Mother Lode and Grass Valley regions in California is very striking and has been noted on page 201. In the California mines barren zones were encountered both along the strike and down the dip, and many properties failed in successful operation until extensive exploration had revealed ore bodies at greater depth. It is believed that further exploration on the Lucky Shot property including judicious crosscutting on the present and deeper levels, would be well justified.

*Ore minerals.*—The ore minerals in the Lucky Shot veins are typical of those throughout the district and include pyrite, arsenopyrite, small amounts of chalcopyrite and sphalerite, tetrahedrite, galena, and free gold. Gold tellurides, which have been reported in the ores from this mine, did not appear in any of the samples studied microscopically. Pyrite occurs in both the vein quartz and the altered wall rocks; its abundance does not appear to have any direct relation to the amount of gold present. Arsenopyrite is, next to pyrite, the most abundant metallic mineral in the ores and bears a higher ratio to the total sulphides in this mine than in the veins farther northeast, where pyrite becomes increasingly more abundant.

*Faults.*—Underground development in the eastern part of the Lucky Shot mine has been limited by a transverse fault which displaces the mineralized lode. This fault comprises a zone of crushed rock, the width of which is unknown but from surface indications is probably more than 65 feet. The fault zone strikes approximately N. 65° W. and dips northeast at an angle estimated to be about 40° to 45°. Drag of the vein near the footwall of the fault indicates that the horizontal component of the displacement was to the right as the observer looks down the dip of the fault. This conclusion is further supported by the position of the extension of the vein or lode system in the War Baby mine, where it is displaced horizontally 600 to 700 feet to the east. Microscopic examination shows that the textural continuity of the rock crystals is destroyed, and individual crystals are much broken and sheared. No direct evidence is available as to whether the fault movement was normal or reverse. The rock mass is considerably kaolinized and exhibits many slips and clay seams.

About 1,200 feet west another transverse fault approximately parallel to the first has been encountered in the 500-foot level. In the north drift on this level the country rock is as badly crushed as it is in the big fault in the east end of the mine; but on the west face of the south drift a zone of small slips was encountered, and the country rock between the slips is firm and fresh. In view of the extremely crushed and decomposed condition of the rock in the north drift as compared with that in the south drift it seems doubtful if this drift has actually penetrated the main fault zone, yet the apparent strike in the north drift should carry it to the position of the slips in the south branch. The two drifts are only 100 feet apart, and the widely different character of the rock in the two exposures is difficult to explain. The displacement of the Lucky Shot vein by the western transverse fault does not seem very great, as the extension of the lode on the south side has been proved on the surface by open cuts and pits for a distance of several hundred yards. The two faults just described cut diagonally across the ridge on which the Lucky Shot is located and may be correlated provisionally with apparent fault zones that cross the ridge east of the Craigie Creek Valley and that are characterized by iron-stained crushed rock mixed with loose earth.

Postmineral movement in the plane of the vein is evident at many places in the Lucky Shot mine. In places slickensides are developed on both footwall and hanging wall, but the gouge is rarely more than an inch or two wide. Mining on the veins has been facilitated by. following the slickensided walls, but these walls do not everywhere follow the somewhat wavy contour of the veins. At some places they break away from the quartz and enter altered wall rock, thus giving the erroneous impression that quartz is lacking or has pinched out. It is therefore especially advisable to do a certain amount of crosscutting where the slickensided walls show considerable hydrothermal alteration.

In the workings above the 200-foot level the continuity of the veins has been somewhat disturbed by minor faults which dip in a direction opposite to the veins but have a nearly parallel strike. A fault of this kind may be observed in the raises from the 200-foot level in the west end of the underground openings. This minor fault with reverse movement in raises 3572, 3566, 3562, and 3573 gradually dies out farther west, where it becomes a barely perceptible roll or buckle. The displacement of the vein by this small fault is rarely more than 3 or 4 feet. In the raises mentioned above the fault itself has broken along a fine-grained dacite dike that is older than the vein, but on this level in the extreme western workings the dike has not been encountered. The dike has recently been encountered in the extreme western workings above the 200-foot level, where it was not displaced by the fault; there the vein passed through the dike as "five or six knife-blade stringers and continued on the other side, the west, as a thin streak of solid quartz, 4 inches wide." [22] It thus appears that the original vein fissures did not break well through the earlier dacite dikes, and when later movement failed to reopen the fissures or displace the dikes, the dikes acted as efficient barriers against circulating solutions. A similar condition was also observed by the writer at the east face of the main level of the War Baby mine.

### WAR BABY

The War Baby mine lies about 1,200 feet east of the Lucky Shot mine and 185 feet below it on the western slope of Craigie Creek. In 1931 the mine was inactive, but the workings were accessible. The original group of four claims was located in 1918 and was taken over by the Willow Creek mines in 1921. Production started in 1923 and continued through 1927, until the shoot above the main working level was largely worked out.

The main haulage level is an adit 175 feet to the vein, which is then followed for about 800 feet by a drift. A winze from the main level connects with a lower drift about 100 feet down the dip of

[22] Communication from W. E. Dunkle.

the vein. This drift was driven under the ore shoot developed above the main level, but the gold content of the ore disclosed by it was considered too low for profitable mining, and this drift has been allowed to fill with water. A map of the War Baby workings is shown on plate 13. The western workings terminate against the fault zone that separates it from the Lucky Shot.

Production from the War Baby mine was confined to a single stope about 175 by 250 feet, the long axis roughly corresponding with the dip of the vein. The ore occurred in a lens, which in places was stoped to a thickness of 10 to 12 feet. Another quartz lens was encountered east of the adit in the main drift (raise 758), but its gold content was too low to encourage development. The average gold content of ore mined from the War Baby is stated to have been $45 a ton.

In the east face of the main drift a dacite dike 3 feet wide was encountered. This dike apparently acted as a dam against circulating solutions, for beyond and above it, to the east, only narrow quartz stringers were found. The dike was broken and displaced by transverse postmineral faults, and the dip could not be determined.

Rock alteration along the vein in the War Baby is the same as that in the Lucky Shot. The early quartz vein filling is massive and coarsely banded and shows brecciation and recementation during the period of deposition. The old raises were not easily accessible, but where observable in the open stopes the dip of the vein is about 30°, or considerably flatter than in the Lucky Shot. The strike is N. 75° E.

Wall-rock alteration in the War Baby mine, the evidence of reopening, and the presence of valuable ore suggest that exploration in depth should discover other ore shoots. Barren zones are to be expected, but the type of mineralization can be expected to have developed shoots for at least several hundred feet below the present workings. In exploring this ground it should be realized that the fault on the west dips under the ground at an angle of not more than 45°, and therefore sinking should be started sufficiently far to the east to allow for going down several hundred feet before the heavy ground of the fault zone is encountered.

### GOLD BULLION

The Gold Bullion property of 16 claims is owned by the Willow Creek mines. The mine is at an elevation of about 4,500 feet, near the top of the ridge that forms the divide between Willow Creek and Craigie Creek. The dismantled camp is on Craigie Creek directly below the mine. The first claims of this group were staked by William Bartholf in 1907 and marked the second discovery of gold quartz veins in the district. The Gold Bullion began production in 1909 and was a steady producer until 1927. In 1911 the original 2-stamp mill was enlarged to a mill with seven 1,000-pound stamps. Relay aerial tramways delivered the ore from the mine to the mill, which is at an elevation of approximately 3,100 feet, or 1,400 feet below the mine.

Ore treatment consisted of crushing and plate amalgamation, concentration of the sulphides for shipment, and impounding the tailings. The capacity of the stamps was 21 tons of ore in 24 hours. By 1918 the mill had been increased to 13 stamps and had a capacity of 50 tons in 24 hours. The tailings were treated in a cyanide plant. The mill was driven by power generated by a Pelton wheel and turbine.

The Gold Bullion has been the second largest producer in the district. The average value of the ore milled is stated to have been about $35 a ton.

The country adjacent to the Gold Bullion vein is broken by faulting into several blocks that have been so tilted as to give considerable variation to the strike and dip of the vein. In general the strike of the vein ranges from N. 25° E. to N. 30° E. and the dip is 12° to 20° W. The mine workings are now caved and inaccessible. The flatness of the vein necessitated the driving of haulageways beneath it. The mine map reveals the labyrinth of horizontal tunnels into which the ore was dumped from the stopes above through numerous chutes. Where erosion had exposed the ore or left it with only a shallow overburden the vein was mined by means of open cuts. The mineralized lode cuts across the top of the ridge and crops out down the dip on the northwest slope. The mine workings are separated into three groups by faults that pass through the ridge with a northwesterly strike. Two of these faults may be correlated with faults exposed in the northwest valley wall of Craigie Creek. Diligent prospecting of the slopes below the Gold Bullion workings has failed to locate the downward extension of the veins, but detailed mapping of the faults in the vicinity might give helpful information for finding the extension of the vein or lode along its strike and in the area between the present workings and the valley floor.

Capps [23] reports that the vein had a maximum thickness of 14 feet in a lens mined through tunnel 5. Ordinarily the ore was 2 to 5 feet thick and pinched to a knife-edge at the limits of the shoots. Much of the rich quartz ore had a bluish tinge, which is characteristic of the high-grade ores of the district.

[23] Capps, S. R., The Willow Creek district, Alaska: U.S. Geol. Survey Bull. 607, p. 69, 1915.

### MARTIN

Three mines on Fishhook Creek have furnished noteworthy production of gold—the Martin, Independence, and Gold Cord. Only partial reports on the production of these mines are available for publication, but their total gold output was worth several hundred thousand dollars.

The Martin mine is on the property of the Alaska Free Gold Mining Co. and is the site of the discovery of gold quartz in the Willow Creek district, in 1906. The group consists of 15 claims on the top and west slope of the ridge north of Hatcher Creek and between Fishhook and Willow Creeks. Two veins have been mined on the Martin property—the Skyscraper and the Homestake veins.

The Skyscraper workings lie just across the gulch from the Independence mine of the Alaska Gold Quartz Mining Co. The vein bisects Skyscraper Mountain and is probably a continuation of the upper vein of the Independence mine. The strike is approximately N. 10° E. and the dip 45° W. The working tunnel of this mine is at an elevation of about 4,500 feet. The accompanying map of the mine workings on the Skyscraper vein (pl. 15) was furnished by J. M. McDonald.

The workings on the Homestake vein are a few hundred feet southeast of the Skyscraper vein and comprise several hundred feet of adits, drifts, and raises. Both mines were only partly accessible at the time of visit, and no adequate data on the underground structure could be gathered. The Homestake vein has a strike approximately N. 10° E. and a dip that ranges from 30° to 42°.

A transverse fault passes between the workings on the Skyscraper and Homestake veins, and another crosses the ridge south of the Homestake workings. Some years ago the Martin and Independence groups were combined with a group of adjoining claims on the west slope of the ridge. A 1,200-foot tunnel was driven in an easterly direction for the purpose of intersecting the Skyscraper, Homestake, and other veins. This tunnel was apparently driven past the point of the projected dip of the veins but without finding them. The reason for this failure appears to be that the faults, which are probably the same as those cutting the Gold Bullion workings, have caused displacements. Alteration of the wall rock in the Martin workings is comparable to that characteristic of the district as a whole, and had mineralized lodes been encountered they would surely have been recognized.

It may be here pointed out that any opening driven to intersect veins in depth from the opposite side of these faults is almost certain to result in disappointment without a careful preliminary determination of the fault movements. Without such a determination exploration in depth should be confined within the limits of the block in which the vein segment is known to exist. The veins on the Martin property are undoubtedly in a zone of hydrothermal rock alteration and gold quartz deposition, which makes it practically certain that they continue downward to considerable depths. It is possible that if the adit from Willow Creek, known as the Brooklyn tunnel, were continued through the fault zones the continuation segments of the Skyscraper and Homestake veins might be found by raising, though such a course is not to be recommended.

The Martin mine has been closed for several years, and the camp and surface plant are now dismantled.

### INDEPENDENCE

The main workings at the Independence mine (see pl. 16) explore two veins that are situated across a small gulch from the Skyscraper workings of the Martin group. The Independence group consists of 17 claims and 2 fractions. The property is owned by the Independence Gold Mining Co.

The upper workings, at an elevation of about 4,700 feet, are on a vein that is regarded as the continuation of the Skyscraper vein of the Martin property. The lower workings explore what appears to be the hanging wall of a mineralized lode that is 25 to 30 feet thick (see pl. 17) but that has never been completely crosscut. As observed along the main drift the strike of the vein is approximately south; the dip is between 10° and 40° W., but the general inclination is about 20°. The vein quartz ranges in thickness from a knife-edge to 4 feet, and the walls are well slickensided. The ore that has been milled in the past is reported to have averaged $30 a ton, and the stopes were more or less confined to areas where ore of that value could be obtained unless otherwise restricted by the narrowing of the vein.

A small fault passes through the ridge between the Skyscraper and Independence mines and is manifested in a distinct roll in the southern exposures in the Independence mine.

Wall-rock alteration has occurred along the Independence vein in the main drift. The gold quartz is banded and where not oxidized is light gray to bluish gray. The ore minerals are the same as those typical of the district as a whole. The mine has been inactive for several years, and the surface plant is completely dismantled.

The vein is of the intermediate-temperature type, and further exploration appears to be well warranted. This exploration should include crosscutting of the mineralized zone from some point on the east slope of the ridge below the present workings.

### GOLD CORD

The Gold Cord claims were staked in 1915 by members of the Bartholf family. The vein was discovered by scraping the thick moss from the truncated portion of a quartz lens, no outcrop being visible. The group is now owned by the Gold Cord Mining & Milling Co. and consists of 9 claims and a fraction. The property is at present under lease to Charles Bartholf, W. S. Horning, and Sidney Black. The principal opening and camp are at an elevation of about 3,900 feet on a bench of the spur between the east and west tributaries of Fishhook Creek near its head.

The camp consists of a mill, bunk house, cook house, and mine shops. The mill is run by semi-Diesel engines and consists of a crusher, a 10-ton Denver mill, amalgamating plates, and a small concentrating table. (See pl. 18 and fig. 32.)

The vein is opened by a shallow tunnel, which at no point attains a depth of 100 feet below the surface or more than 180 to 200 feet on the dip of the vein. The vein strikes N. 10° W. and dips 30°–42° W. The tunnel, which cuts the vein just below the glory hole, extends north for a distance of 630 feet to a point at which it cuts one of the transverse faults of the district. The southern part of the vein consists of a stringer lode only partly exposed in the drift. This section of the vein showed a good tenor for a distance of 40 feet before it dipped below the bottom of the drift near station 5, about 225 feet in from the portal. From this point northward the drift for some distance followed a nearly vertical slickensided fault plane until between 360 and 495 feet from the portal it intersected the truncated base of another ore shoot. This shoot was supposedly mined out, as the quartz had pinched to 2 or 3 inches, but in 1931 Bartholf, Horning, and Black drove a raise from the north lobe of the old stope and cut into a new lens which ranges from 6 to 14 feet in thickness. Much of the ore from this new shoot is reported to carry more than $50 a ton in gold, and at last reports there was 14 feet of ore in the face that averaged $45 a ton. The extent of this shoot along the strike and up the dip has not been determined. In September 1931 the two raises north of the stope were not up far enough to have encountered the new lens. The quartz in this lens is massive and both white and bluish gray, the difference in color being due to differences in the relative amounts of sulphides present. The dark quartz overlies the white quartz and is separated from it by a slickensided fracture parallel to the plane of the vein. Another slickensided plane is parallel to the top of the lens and in places has free gold burnished onto it. The earlier quartz is much broken and recemented with later quartz.

Most of the gold occurs in very small particles. It is associated with pyrite, arsenopyrite, tetrahedrite, and galena and minor

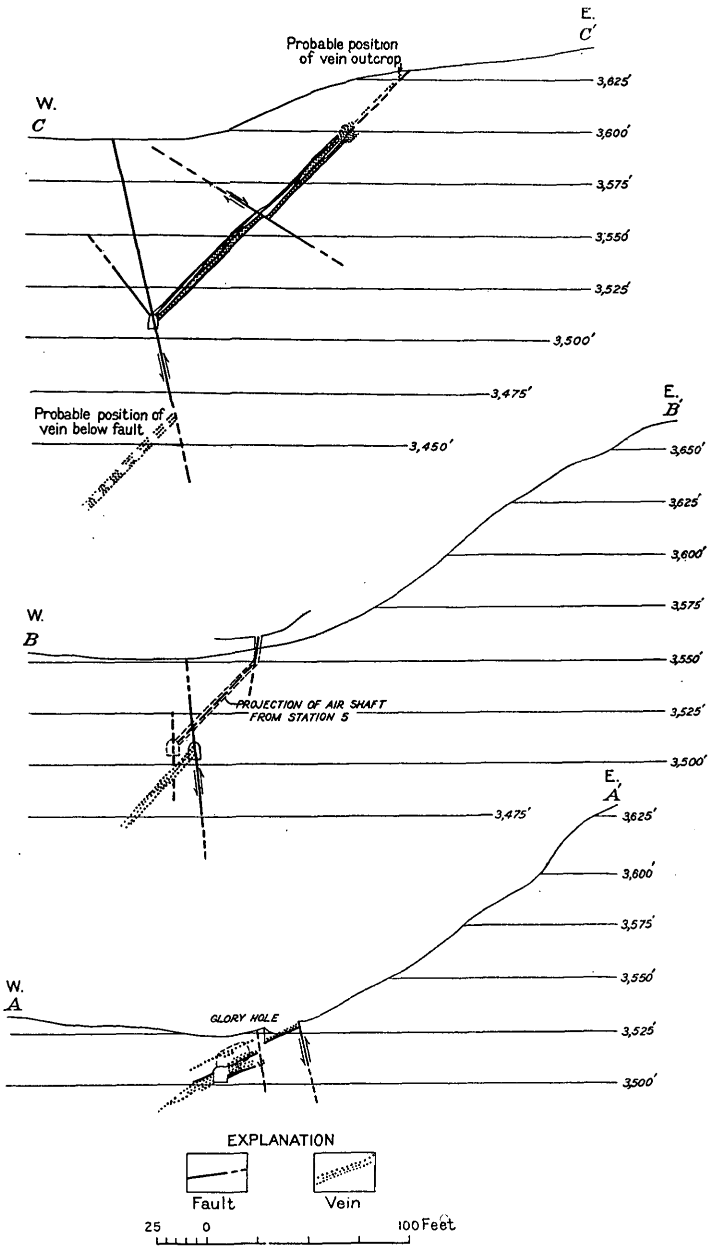



FIGURE 32.—Sections of Gold Cord mine. For lines of sections, see plate 18.

amounts of chalcopyrite and sphalerite. As elsewhere throughout the district, the gold appears to have been the latest metallic mineral deposited.

Wall-rock alteration was intense and consisted of replacement by the usual hydrothermal minerals of the district—chlorite, pyrite, sericite, ankerite, and a little calcite. Here and there arsenopyrite has also been deposited in the wall rock. Pyrite occurs in greater proportions in the ore of the Gold Cord mine than it does in the Lucky Shot and War Baby mines. There is an apparent increase in pyrite toward the northeast, along the mineralized belt.

The downward extension of the vein on the west side of the steeply dipping north-south fault along which the drift was carried has been drifted with respect to the vein east of the fault. The vein disappears under the floor of the drift near station 5, but the pitch of the angle of intersection between the fault and the vein could not be accurately measured, though the distance down the fault to the vein increases to the north. A winze at an angle of 45° was sunk from the drift at the south end of the stope to a depth of 45 feet, but it did not encounter the vein, which has a dip of 45°. This result might have been expected, for the winze was started above the vein and was gaining depth at an angle less than that of the vein, because although the winze had the same inclination as the vein, it was sunk at an angle of about 45° to the strike of the vein.

Sampling under the track 50 to 80 feet south of station 5 indicates that the gold is confined to the quartz. The "fill" consists of highly altered and bleached country rock. A small crosscut at station 3 shows a dying out of the quartz stringers, and the main quartz vein probably lies below the level of the drift. As the vein is cut off by the north-south fault, it would probably be advisable to sink before crosscutting to determine the limits of the mineralized zone. The gold content of the ore at this point warrants such exploration. From a shaft the vein could be prospected by a drift to the north, and thus the down-faulted portion of the ore shoot could be developed.

The vein is cut off on the north by a transverse fault beyond which the vein has not been definitely located, although quartz stringers in altered rock have been found about 150 feet to the east. That the continuation of the vein must lie to the east is indicated by the bending back of the minor fracturing on the south side of the fault. Another transverse fault probably cuts the vein somewhere in the valley floor below the mill building. This fault may be seen in the face of the steep cliffs about 350 feet east of the bunk house, and its extension westward is suggested by a series of slight depressions and springs. What may be a southward continuation of the Gold Cord vein has been exposed in prospect pits that extend for several hundred feet southward across Fishhook Valley.

The proved occurrence of an ore shoot in the Gold Cord vein and the wall-rock alteration indicate that important circulatory channels have existed in this portion of the mineralized zone. Exploration work in depth is clearly warranted, but it can be judiciously accomplished only by sinking, as the topographic relief is slight along the proved part of the vein. An additional depth of at most 75 feet below the present drift is all that would be gained by driving an adit or crosscut from a point between the mill building and the bunk house. Though such work would probably encounter ore, yet it would add little to the exploration of the vein in depth and would further delay real development of the property.

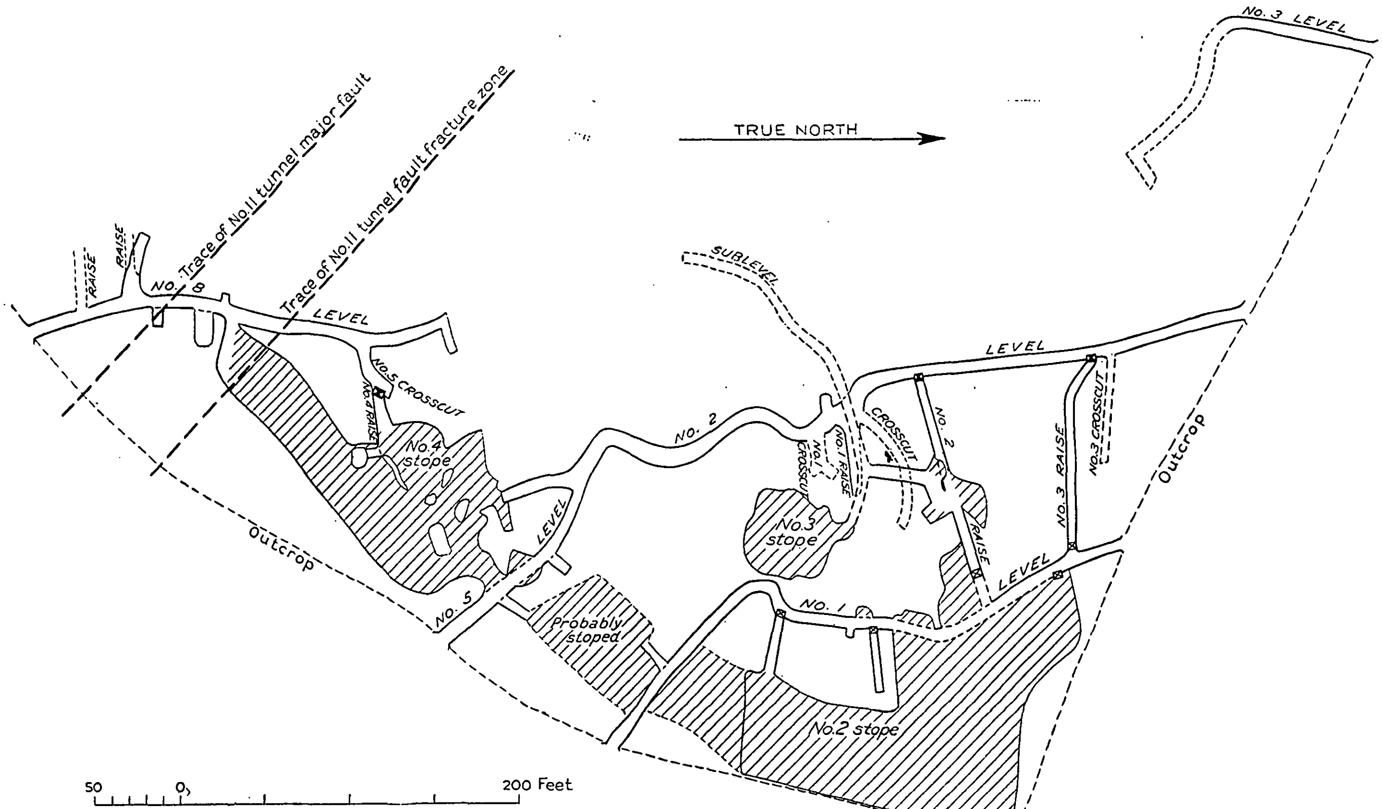
### HIGH GRADE

The High Grade property is about half a mile northeast of the Gold Cord mine, at the head of Fishhook Valley. Very rich "specimen rock" has been obtained from a quartz stringer 1 to 2 inches wide. In 1930 a ton of this ore was shipped to the Tacoma smelter and netted the owners, Herman Kloss and Heinrich Snider, over $1,200. The larger of two quartz stringers has been followed by a drift, and quartz as much as 12 inches thick developed a few tons of low-grade ore.

The presence of ankerite in the altered wall rock and vein "fill" shows that the stringers are part of the main mineralized zone, but the work to date has failed to prove the presence of commercial ore bodies.

### MABEL

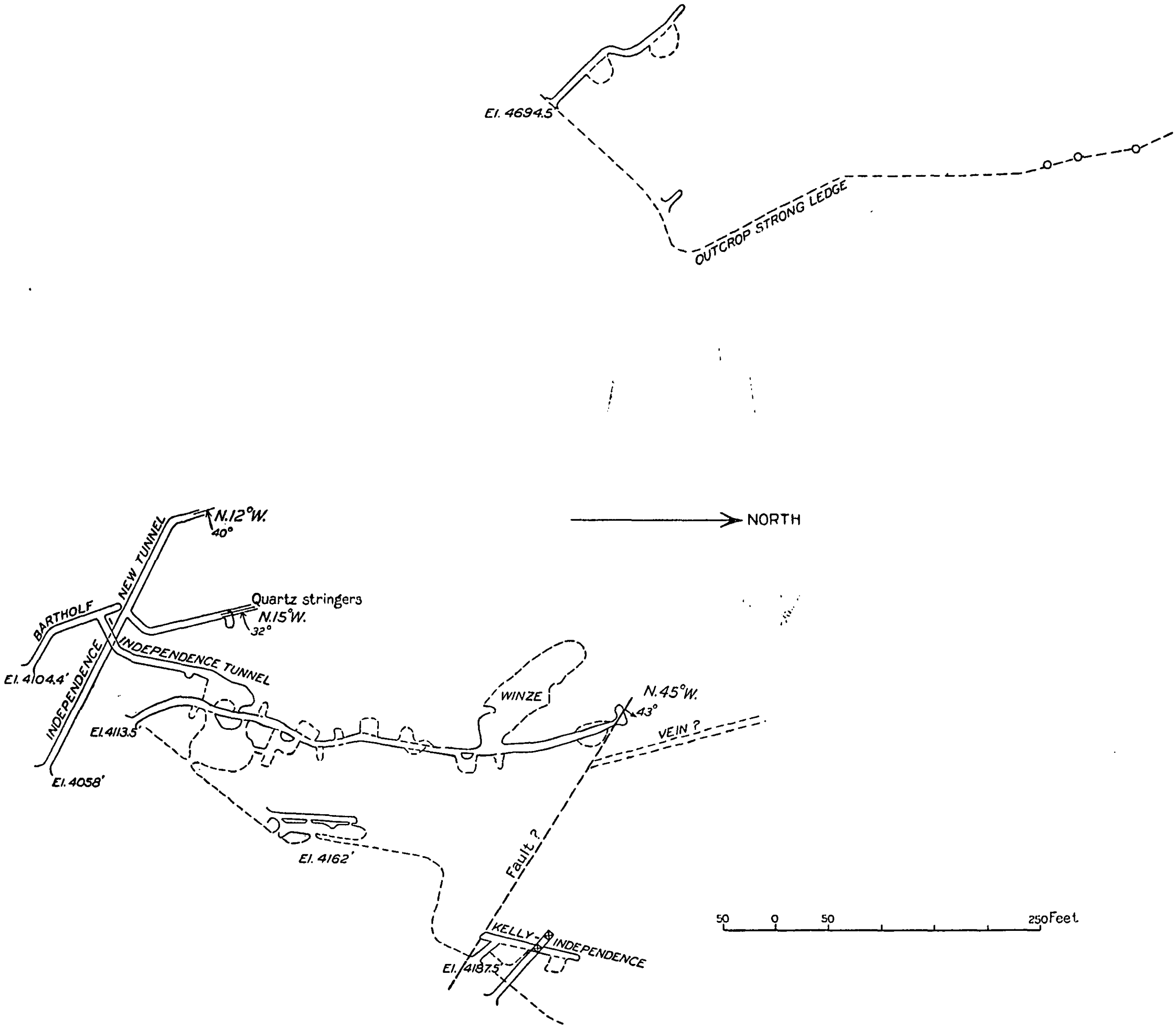
The Mabel mine is the only property on Reed Creek that has produced any considerable amount of gold in the past. It is situated near the top of the ridge between Reed Creek and Sidney Basin. The group consists of 10 claims so placed as to cover the known lateral extent of the mineralized lode. The mine has been intermittently worked since 1912, and during this period its total production has probably been worth more than $100,000. The ore probably averaged over $30 a ton. The mill and camp buildings are situated at the base of the ridge, about 1,400 feet below the mine. The mill is operated by water power, and its equipment consists of a 10-ton Denver mill, amalgamation plates, a small concentrating table, and several vats for cyaniding the mill tailings. A combined bunk house and blacksmith shop is perched on the steep slope near the portal of the main tunnel. The mine is developed by two drifts on the vein and several winzes below the lower drift. (See pl. 19.) The workings above the lower tunnel are now inaccessible, and the map of this part of the workings was taken from an early compass survey by W. E. Dunkle.



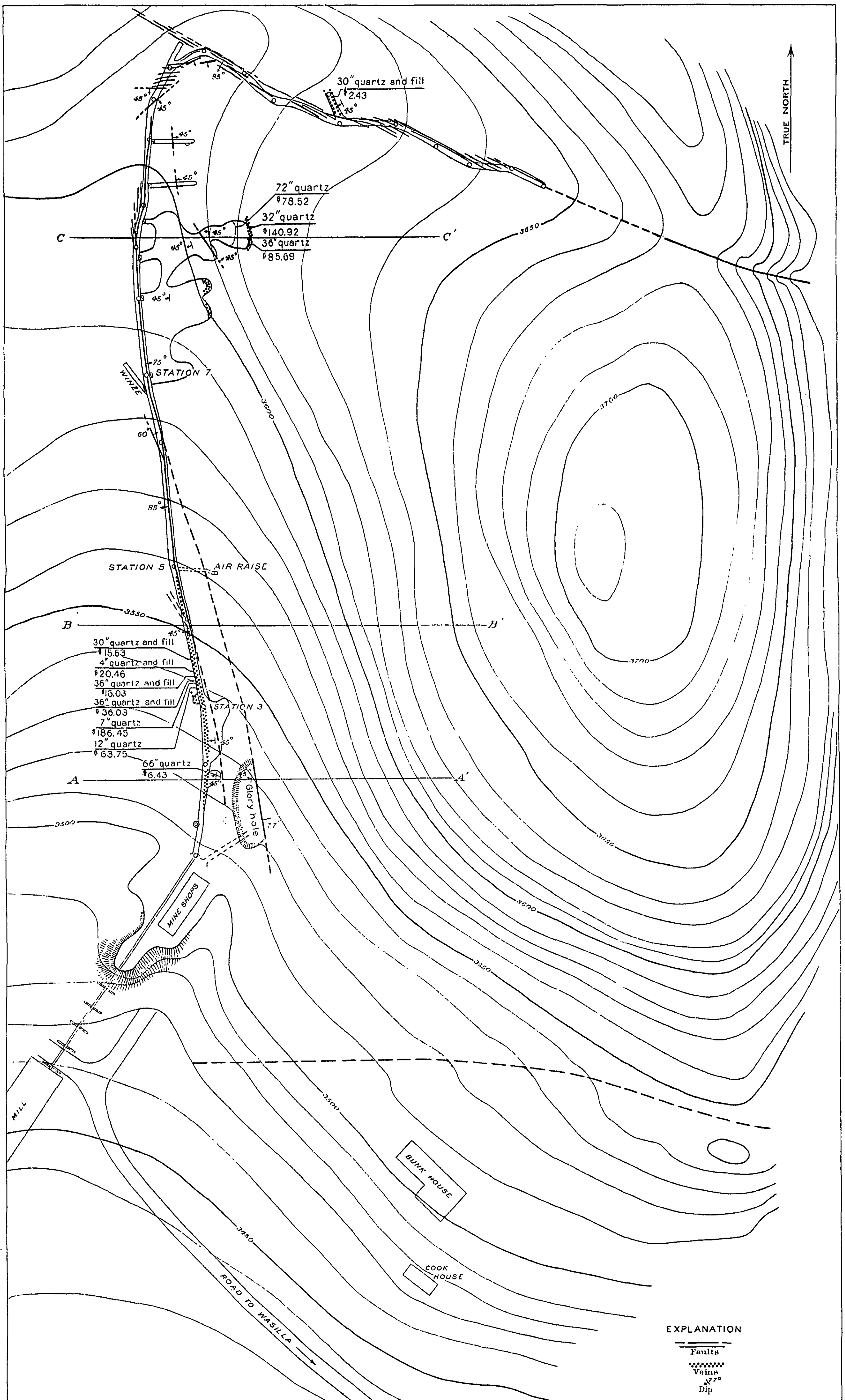

WORKINGS ON SKYSCRAPER VEIN, MARTIN MINE.

INDEPENDENCE AND GOLD CORD MINES.

Independence mine in center. Gold Cord mine and camp across valley to right. Shows rhombic jointing in quartz diorite. Dark area to right of Independence dump is the mineralized zone dipping into the mountain.

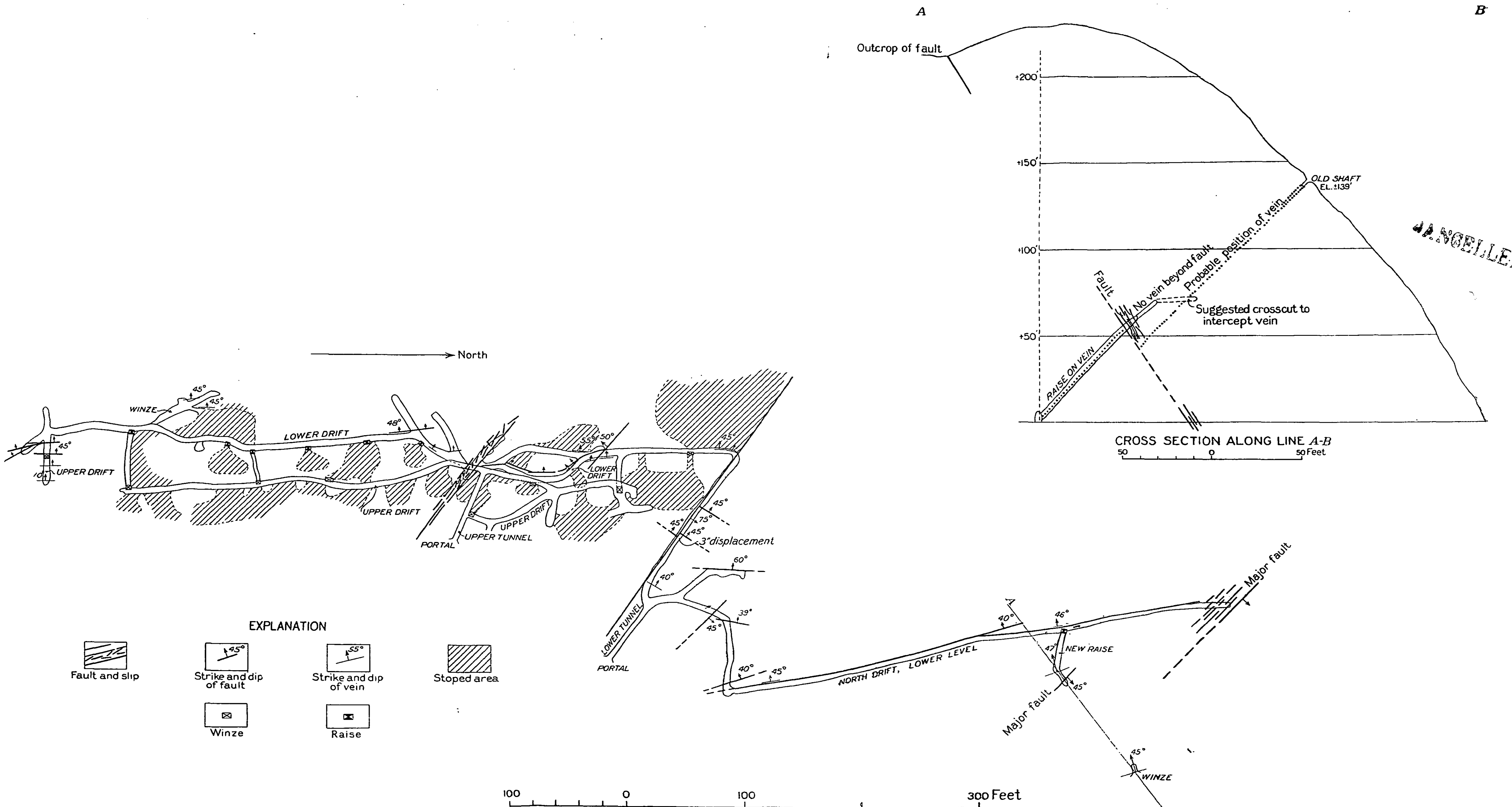



MAP OF WORKINGS OF INDEPENDENCE MINE.

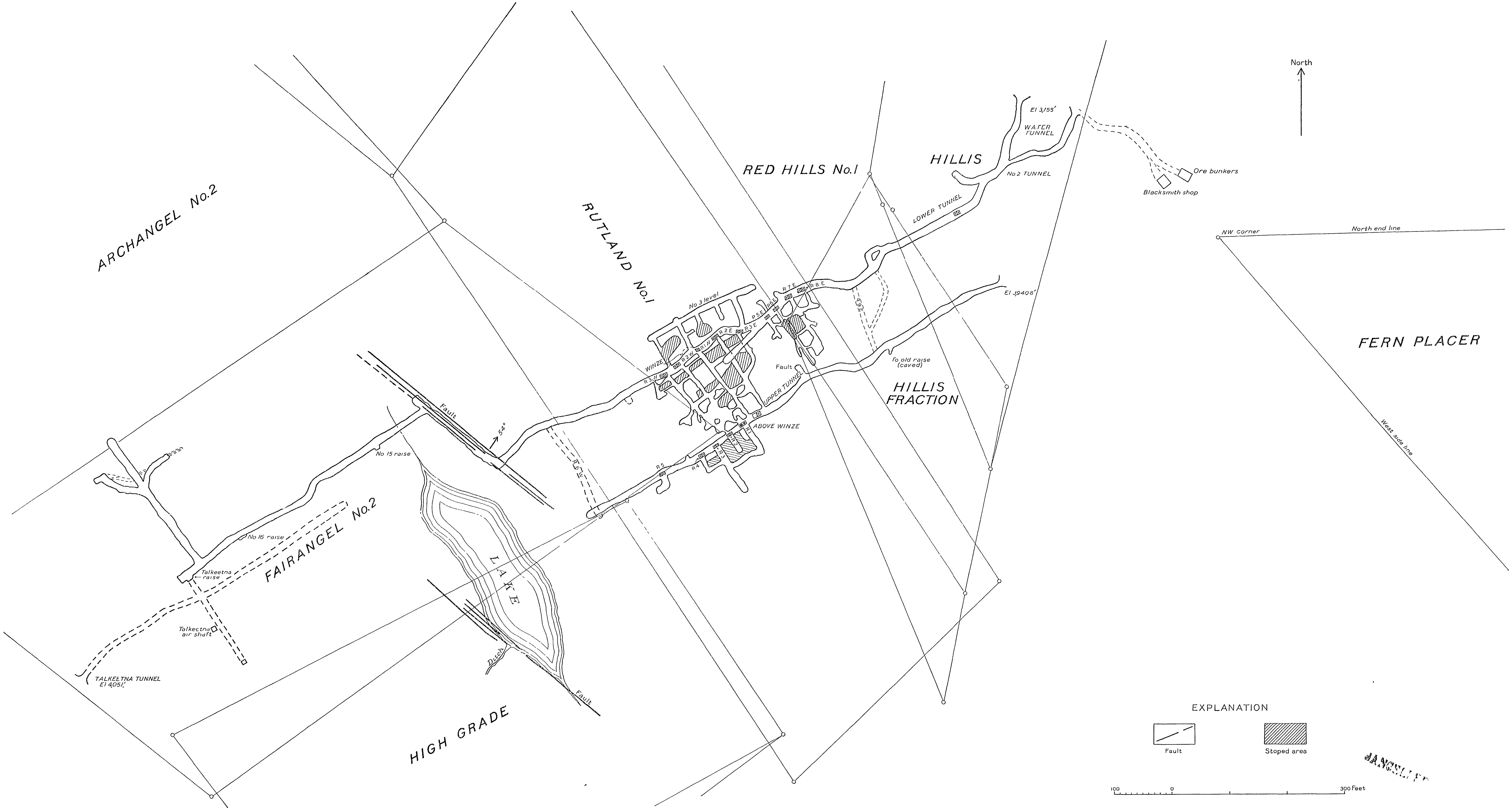



## MAP OF GOLD CORD MINE.

For sections along lines *A-A'*, *B-B'*, *C-C'*, see figure 32.




MAP AND SECTION OF MABEL MINE.




MAP OF WORKINGS OF FERN MINE

Gold occurs in the ore of the Mabel mine associated with pyrite, arsenopyrite, tetrahedrite, galena, and very minor amounts of chalcopyrite and sphalerite. In some specimens of rich ore taken near the surface the abundant copper stain appears to be due to oxidation of tetrahedrite.

At the present time the proved ore has been rather completely mined out, but the stopes indicate that it occurred in lenses of considerable thickness. All observable working faces in the southern part of the mine show that the vein pinches and that it was much disturbed by faults, which have broken the ground into small blocks with undetermined displacements. Pinching of the veins is common throughout the district and does not preclude the existence of valuable ore lenses beyond, but the faulted condition of the ground in this part of the mine will require that in planning future developments careful analysis should be made of the conditions.

The lower or main drift, which is about 35 feet below the upper drift, is entered through an adit driven along a slickensided post-mineral fault plane. At its intersection with this fault the vein is bent back into the fault, indicating that the north extension of the vein has been left to the east. Inspection of the mine map will show that the vein on the south has been stoped up to the fault, giving support to the inference that an ore shoot has been truncated by the fault. The vein found north of this fault has failed to show ore, although it contains from 1 to 3 feet of quartz and is continuous for a distance of 450 feet to the north to the point where it is cut off by a transverse zone of crushed and decomposed quartz diorite.

The southern part of the vein has a general strike of N. 5° W. and an average dip of 30° W. The north vein has a strike of N. 12° W. and a dip of 45° W. The quartz in the southern part of the vein shows evidence of much reopening and cementation by later quartz and a tendency to form bulging lenses, whereas that in the northern part is much more massive and undisturbed and continues throughout its length with a fairly even width. Wall-rock alteration appears to have been about equal in the north and south parts of the mine and consisted of chloritization, sericitization, and ankeritization. On the whole it appears that the two parts of the mineralized zone or lode now in juxtaposition on the two sides of the fault in the adit have been brought to that position as the result of considerable movement in the plane of the fault, and it is by no means unlikely that they may actually be parts of different veins.

A raise from the north drift encountered the north transverse fault and failed to connect with the vein above it. The outcrop of this vein on the surface shows a good tenor in free gold. Crosscutting to

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the northeast from the top of the raise would probably disclose the part of the vein above the fault.

Conditions appear to have been favorable for the deposition of ore bodies in the mineralized zone of the Mabel property, but further exploration seems likely to be expensive, as the relations in the much-faulted ground are exceedingly difficult of interpretation and evidence on which to base the search for the displaced segments of the vein is absent.

## FERN

The Fern mine is situated on the west side of Archangel Creek, on the spur of the ridge between Archangel and Fairangel Creeks. An automobile road, good though in places steep, gives ready access to the property from the town of Wasilla, on the Alaska Railroad about 24 miles distant. The property consists of a group of 17 claims, including those formerly held by the Talkeetna Mining Co. on Fairangel Creek. The surface equipment at the Fern mine included two mill buildings, a bunk house, several smaller dwellings, an aerial tramway from mine to mill bunkers, and a blacksmith shop near the mine portal. One mill building was equipped with jaw crusher, a 20-ton Denver mill, amalgamation plates, and concentration table. A 40-ton cyanide leaching plant was housed in a separate building. It has been reported that during the winter of 1931–32 certain of the camp buildings were destroyed by a snowslide.

The Fern mine was inactive after 1927 until 1931, when T. S. McDougal and associates cleaned out the lower drift (tunnel 2) and extended two raises on the vein (9 east and 6 west).

The property has been developed by two tunnels at elevations of 3,940 and 3,755 feet, or one 185 feet above the other. (See pl. 20.) The upper tunnel is inaccessible, and certain stopes that had been mined above it could not be entered; the stoped areas indicated on the mine map are therefore incomplete. A winze was sunk opposite raise 1 west for a distance of 90 feet on the dip of the vein, whence a sublevel (level 3) was driven along the vein for a total distance of 200 feet. The raises and stopes from this sublevel are now flooded and inaccessible.

The lower tunnel (no. 2) was driven 1,200 feet along the vein, which has a strike of S. 65° W., to a point where it is intercepted by a transverse fault that strikes N. 50° W. and dips steeply northeast. The drift followed this fault in a northwesterly direction for 180 feet, then left it and continued along quartz stringers in a southeasterly direction for 530 feet to a point at which it was under the old Talkeetna workings. From this point a raise was put up on a quartz stringer, which was expected to connect with the Talkeetna tunnel. This raise reached the surface about 110 feet southeast of the air shaft on the Talkeetna vein. From a point near the west face of the drift a crosscut was driven northwest with the hope of finding the vein on Talkeetna property, which was thought to be the faulted portion of the vein of the Fern mine. After exploration in this direction for a distance of 260 feet had failed to disclose a promising lead all work south of the transverse fault was abandoned. It seems probable that the Talkeetna vein would have been encountered had the crosscut been continued 50 to 100 feet farther, as is indicated by projecting the dip from the Talkeetna workings. A possible explanation of the reason why the crosscut was not continued farther to explore this zone is afforded by a comparison of the survey map furnished by T. S. McDougal with old profile drawings at the mine. This comparison shows that there was a discrepancy in figuring the difference in elevation between the lower tunnel of the Fern and the tunnel of the Talkeetna mine. The elevation of the portals, as given on plate 20, is 3,755 and 4,051 feet, respectively. Allowing 1 foot rise to 100 feet advance, the tunnel elevations in the vertical plane of the Talkeetna raise would be 3,780 and 4,054 feet, a difference of 276 feet. Cross-section drawings of the mine indicate that a difference in elevation of 196 feet was used in figuring the point at which the Fern crosscut should intersect the downward projection of the Talkeetna vein.

It appears also to be significant that the Fern vein is bent southward as it approaches the fault. There is no notable number of minor oblique slip planes, such as are frequently observed at the intersection of a fault with a vein; instead the stresses appear to have been relieved by the breaking up of the vein material, and this breaking becomes increasingly intense with approach to the fault. This was especially evident in raise 6 west, where even the footwall country rock to a thickness of 2 feet has been reduced to a rubble embedded in finely comminuted material. It is therefore entirely possible that the displacement of the Fern vein is not as originally conjectured but is from the southeast and that the Fern vein is not the extension of the Talkeetna vein.

Hydrothermal wall-rock alteration in the Fern mine has been similar to that in the other properties described, but ankerite has been found to a greater extent—in fact, ankerite veinlets in the country rock near the vein are more abundant than elsewhere in the district. The ankerite is everywhere intergrown with secondary quartz, which destroys its normal cleavage and increases its apparent hardness. This intergrowth is light creamy to white in color, and the mineral is generally referred to in the district as "spar." Within the mineralized lode the tabular partitions of country rock between quartz stringers are in general highly ankeritized. Where the wall rock is exposed by the transverse fault ankerite veinlets as much as 4 inches thick are common.

The crushed rock is highly kaolinized in the transverse fault zone as well as in regions of intense postmineral movement along the vein. Where the rocks are much altered, kaolin occurs in soft clay-like masses, which make "swelling ground", and in these places the mine workings are difficult to keep open. In the crosscut opposite raise 5 east on the second level kaolinization has softened the country rock between the quartz stringers so that the rock is constantly breaking off. In this crosscut postmineral movement in the plane of the lode has broken the closely spaced quartz stringers and the intervening country rock, providing many channels for the circulation of surface water, which produces the kaolin as an alteration product of the feldspars.

The mineralized zone in the Fern mine, as exposed in the underground developments, shows the quartz deposited in a major fracture and in a series of parallel stringers in the hanging and footwalls. This structure reaches its maximum development in the stoped area, where it has an observed thickness of 18 feet. In the crosscut from the lower tunnel opposite raise 5 east the hanging-wall zone is 14 feet thick and consists of closely spaced quartz stringers in highly altered quartz diorite. The rock is much broken by postmineral movement in the plane of the lode. Next below this zone is 1 to 2 feet of massive white quartz that marks the principal premineral fracture. This massive quartz rests on a slickensided wall of altered quartz diorite. Below the slickensided wall is a zone 3 feet thick composed of quartz stringers in altered country rock. undisturbed by postmineral movement. (See fig. 33.) Channel samples yield the following assay returns: 12 feet in hanging-wall zone, $21.06; massive quartz 8 to 14 inches, $9.32; 2½ feet in the zone underlying the slickensided wall, $47.32.

In the hanging-wall side of the lower tunnel (no. 2) near station 9, several quartz stringers are exposed for a short distance. The total thickness of the zone of which they are a part could not be determined, but it is certainly at least 2 feet. Selected specimens of the quartz from these stringers assayed $98.52, and probably a sample across 2 feet of the zone would yield an average of $30 to $40 a ton in gold.

The main quartz lead, which has been followed by the drifts, branches on the lower level at a point about 650 feet from the portal and on the upper level at a point about 600 feet from the portal. The branch vein has well-developed slickensided walls but has been followed for only a few feet. Its dip is about 55°, or considerably steeper than that of the main vein. In the Fern mine, as in the

Lucky Shot mine, there is an apparent tendency for rich ore shoots to form in the vicinity of the junction of the main vein and a branch, but developments have not advanced sufficiently to show that this condition actually prevails at this place. In the Fern mine, as in the other properties, the gold is principally associated with late quartz and is the last metallic mineral to be deposited. It is associated with pyrite and arsenopyrite, also with tetrahedrite and galena, which were themselves later than the pyrite and arsenopyrite and introduced with the second generation of quartz. The carbonates, calcite and ankerite, have been deposited in tiny veinlets that are later than the youngest vein quartz.

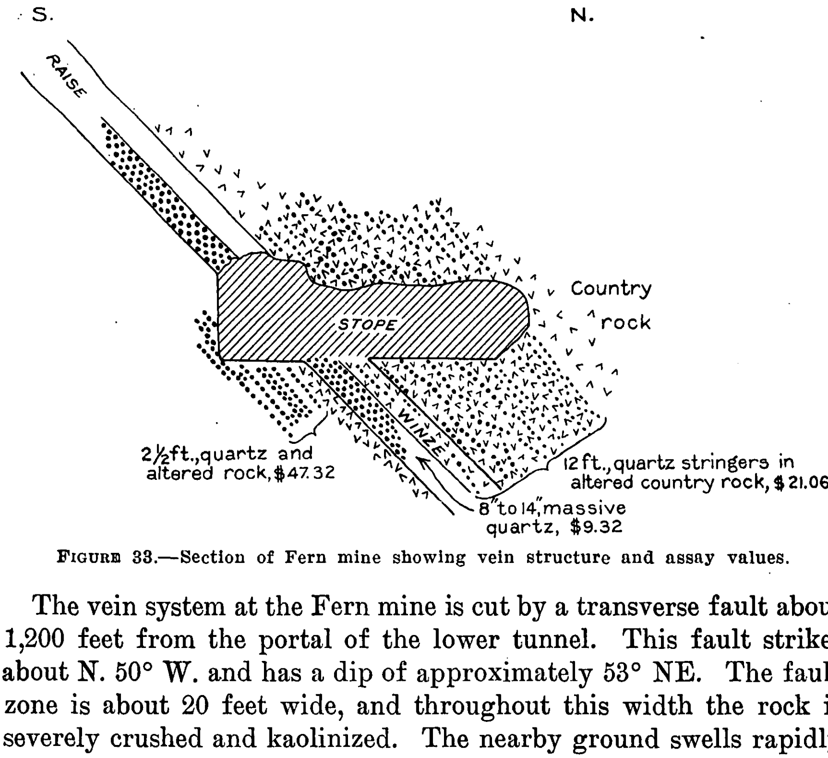


FIGURE 33.—Section of Fern mine showing vein structure and assay values.

The vein system at the Fern mine is cut by a transverse fault about 1,200 feet from the portal of the lower tunnel. This fault strikes about N. 50° W. and has a dip of approximately 53° NE. The fault zone is about 20 feet wide, and throughout this width the rock is severely crushed and kaolinized. The nearby ground swells rapidly and is hard to hold. The slickensided planes of this fault may be recognized on the southwest bank of the small lake shown on plate 20. If the Talkeetna vein is the southwestern extension of the Fern vein this fault has caused a horizontal displacement of at least 480 feet, but probably not more than 550 feet.

Postmineral movement in the plane of the vein appears to be more intense than has been observed elsewhere in the district. This condition is very clearly shown at a point 193 feet above the lower tunnel in raise 6 west. Here many slips come into the vein from the hanging wall and cut through the ground-up mass of quartz and country rock. Farther up the raise the broken quartz has been rolled and worn into round fragments. A similar condition was also observed in raise 9 east, at the opposite end of the stoped area. There fragments of the broken quartz veinlets and associated material assayed $10.83 to the ton, but the material is so broken and mixed that sorting is impossible. All raises have been driven between a certain set of slickensided walls, yet exposures in the drift below show higher tenor below and above these walls. The necessity for further crosscutting to determine the full thickness of the mineralized zone is clearly indicated.

The general conditions in the Fern mine may be summarized as follows: The Fern vein is of the stringer-lode type and shows no notably thick quartz lenses. Assays indicate that the thickest quartz stringers do not carry the most gold. The maximum thickness of the stringer zone which could be observed was 18 to 20 feet. Wall-rock alteration has been intense, and the gold is associated with the late quartz and metallic minerals of the vein. The gold content appears to be lower in the Fern mine than in the mines on Fishhook and Craigie Creeks but is sufficiently high to encourage development. Well-directed exploration should reveal valuable ore shoots. Such exploration should include carefully planned crosscutting from the present openings as well as drifting and crosscutting on deeper levels.

### STILES

The Stiles property, formerly known as the Shough property, is now owned by A. W. Stiles and associates. It is at an elevation of about 3,400 feet on the western valley wall of the Little Susitna River, about 2 miles north of Fishhook Creek. It is reported that in the past several rich quartz stringers were opened on this property, but the surface cuts are now caved and the veins cannot be seen.[24] In 1931 the property was of special geologic interest because an adit was being driven to crosscut the large aplite dike that occurs there in the hope of finding the vein that is supposed to parallel it on the north. The tunnel had been driven a distance of about 270 feet, the last 100 feet in aplite. The actual distance to the vein is uncertain, as the dike has been disturbed by movement which has brought blocks of quartz diorite into the fault zone. The aplite itself shows evidence of hydrothermal alteration and is pyritized and sericitized, thus giving added indication that the solutions that formed the veins were later than the aplite dikes. The aplite dike on the Stiles property is the largest and most persistent one in the district. It can be traced more or less continuously from a point

[24] Capps, S. R., The Willow Creek district, Alaska: U.S. Geol. Survey Bull. 607, pp. 75–76, 1915.

just west of the pass between Hatcher and Willow Creeks to Idaho Peak and beyond, a distance of more than 6 miles. On the Stiles property the dike has an apparent dip to the north, but this may be the result of faulting.

### GOLD MINT

The Gold Mint property belongs to the Marion Twin Gold Mining Co. The workings are on the southeastern slopes of the valley of the Little Susitna River about 2½ miles above its junction with Reed Creek. A well-constructed 5-stamp mill was installed near the river below the camp. Power for the operation of the mill and the air compressor is furnished by water piped from Lone Tree Gulch. During the season of 1931 the road from Fishhook to the camp was improved, and it is now in good condition for automobiles and trucks. The lower workings of the Gold Mint are situated just above the talus and south of the outlet of the first cirque south of Lone Tree Gulch, at an elevation of about 3,000 feet. They consist of two tunnels and some open cuts that explore narrow quartz stringers from which a few tons of ore has been obtained. The wall rock is a fine-grained quartz diorite which shows the development of some chlorite. These veins are probably connected genetically with the larger vein described below.

The upper tunnel of the Gold Mint is at an elevation of approximately 3,400 feet and is located on the southwestern spur of the ridge between the cirque and Lone Tree Gulch. It had been driven toward the southeast on a vein that strikes in general N. 35° W. and dips 40° SW. At a distance of 400 feet from the portal the vein is cut off at an acute angle by a fault with a steep dip to the southwest and a strike of N. 60° W. The drift was continued for 130 feet beyond the fault intersection without leaving the zone of crushed rock. The ground through which it was driven does not stand well, and the opening is now closed. If there is no change in the angle between the bearing of the drift and the strike of the fault, the width of the fault zone is in excess of 70 feet.

It is reported that ore carrying $30 in gold to the ton was found in a winze (now flooded), and a lower adit was driven to intersect the vein 180 feet below. This adit had just encountered the intersection of the vein and fault at a distance of 130 feet from the portal when work was discontinued in 1931. On this lower level the dip of the fault was 70° NE., but the average dip is probably almost vertical. The converging of the vein (dip 45°) toward the vertical fault and the acute angle between their respective strikes (about 30°) leaves only a small triangular portion of the vein accessible to exploration. Therefore, unless the faulted portion of the vein can be located on the surface or beyond the fault there is only a small amount of vein material available in the tract being explored by the adit.

In the upper tunnel the vein quartz is from a few inches to 2½ feet in thickness and the "fill" has been altered by the deposition of sericite, ankerite, and pyrite, which indicates that the vein is of the intermediate-temperature type.

### MISCELLANEOUS PROSPECTS

The Clyde Thorpe property is located in the mica schist area on the spur between the east and west branches of Grubstake Gulch. Developments there consist of shallow tunnels driven on quartz stringers that trend parallel with the strike of the cleavage in the mica schist. Four of these stringers have been exposed by open cuts and the shallow tunnels. The stringers range in width from a fraction of an inch to 3½ feet. Oxidation between the walls is strong, and some concentration of gold appears to have resulted from this action. A sample cut across a 16-inch band in the face of the upper tunnel assayed $25.92; another sample of 2 feet between walls in the lower tunnel assayed $19.72; and another taken 10 feet beyond in the lower tunnel assayed $8.52. The tenor is not constant along the strike of the stringers exposed in the tunnels. The gold occurs principally as the native metal, but it contains more silver than that from the veins in the quartz diorite. It seems evident that the placer gold occurring in Grubstake Gulch and in Willow Creek was derived principally from erosion of these and similar veins that may be present in the schists.

There are other properties within the quartz diorite massif of the Willow Creek district which have veins exposed by surface work or shallow tunnels. The location of some of these properties is indicated on plate 11. None of the properties examined by the writer disclosed any notable features or departed from the types already described in detail, and the small amount of development work that has been done on them does not furnish adequate facts on which to base a judgment as to their potential resources. Most of them have been described by Capps and Chapin and in the annual bulletins published by the Geological Survey on the mineral industry of Alaska.

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