GEOLOGY AND ORE-DEPOSITS OF THE MT. INGALLS DISTRICT

PLUMAS COUNTY, CALIFORNIA

A THESIS SUBMITTED TO THE DEPARTMENT OF GEOLOGY AND
THE COMMITTEE ON GRADUATE STUDY OF LEAND STANFORD
JUNIOR UNIVERSITY, IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS

Sydney C. Ewing
June 1927
Approved for the Department.

[Signature]

Approved for the Committee.

[Signature]
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ACKNOWLEDGEMENT

The research embodied in this report was carried on at the Walker Mine, and in the laboratories of the Department of Geology of Stanford University. The author wishes to express his indebtedness to the officials of the Walker Mining Company, in particular H.R. Tunnell, H.A. Geisendorfer, P. Billingsley and C. de Arrieta, for their courteous assistance in the prosecution of this study; and to Professors C. F. Tolman, A. F. Rogers, and S. W. Young for their interest in the work, and for many helpful suggestions and criticisms.
I

INTRODUCTION.

Location of the District.

The Mt. Ingalls district is in Plumas County, California, (Fig. 1, p. 2) and lies between Genessee Valley and the canyons of Little Grizzly Creek and Red Clover Creek. Topographically it comprises the block of which Mt. Ingalls is the highest point. It may be reached by road from Portola, on the Western Pacific Railroad. Walker Mine is twenty miles distant from Portola by road. The north side of Mt. Ingalls block may be reached from Genessee, which is connected by road with Taylorsville and Indian Valley.

Industries.

The Mt. Ingalls district is a part of the Plumas National Forest. It is heavily wooded, but owing to the inaccessibility lumbering operations have not yet reached the district. The chief industry is mining, and the district ranks second to the Engels mine among the copper producers of California. The metals produced are copper, gold and silver. The only other industry is the pasturing of a few bands of sheep in the spring of the year. The Walker mine, of the Walker Mining Company, is the only present mineral producer. This company, in 1926, mined from 500-750 tons of ore per day. The ore is treated
Fig. 1 - Sketch map of a portion of California and Nevada, showing location of Mt. Ingalls district (shaded). Scale, 30 miles to 1 inch.

by the flotation process, and the concentrates are shipped by a nine-mile aerial tramway over the Grizzly Mountains to Spring Garden on the Western Pacific Railway. The concentrates are shipped to the Salt Lake district, Utah, for smelting.
Purpose and Scope of the Work.

Although the Walker Mine is a notable producer of copper, no description of the geology of the mine has been published. In view of the interesting features of the Engels mine, at the northern end of the Genesee belt, described by Turner and Rogers\textsuperscript{18}, and Graton and McLaughlin\textsuperscript{19}, a study of the Walker mine deposits was commenced in 1925, and continued in 1926, in the hope of obtaining some information on magmatic ore deposits. In this work it was necessary to study the surface geology in some detail. The geology of the region north of the Fortieth Parallel was described by J.S. Diller\textsuperscript{1} in 1905, and that immediately south of this parallel by H.W. Turner\textsuperscript{2}, in the Downieville Folio of the U.S. Geological Survey, in 1895. The small-scale map of the Downieville Folio was insufficiently detailed for the purpose, and in the summer of 1925 the geology of the vicinity of Walker mine was mapped by the author on the large-scale topographic sheets of the U.S. Forest Service. In this work the stratigraphic work of Diller in the Taylorsville region was followed in detail. Some information was also derived from a geological map of the Walker Bros. Consolidated claims, by S.H. Ball, in the office of the Walker Mining Co. In the description of the geology of the Mt. Ingalls district the information from these sources is compiled,
with additional information secured by the author, particularly the results of petrographic studies of the rocks of the district.

In the study of the Walker mine geology and ore occurrences, use was made of the geological and other maps of the Walker Mining Co., compiled by P. Billingsley, T. Lyon, C. de Arrieta, and others. No access was had to the reports of the Company's geologists. Some of the Company's data is reproduced in the accompanying plates and maps, by permission of the Company. The attempt was made to secure additional information of a scientific nature by detailed observations underground and by microscopic examination of the ores and country-rock. The descriptions of the economic geology of the district are based almost entirely on this independent work.

The purpose of this report is to present a comprehensive description of the geology and ore deposits of the Mt. Ingalls district, especially of the vicinity of the Walker mine, drawn from all available sources. Especial stress will be laid on details bearing on the problem of the genesis of the ores of the district. It is hoped that the data herein presented may be of assistance to geologists working in this region, and may be of some interest in the study of ore deposits in general. The variety of types of ore-deposits, of igneous rocks, and of the products of various metamorphic processes, which
are developed in this small district, has made the detailed study interesting and instructive to the author; the laboratory work has involved the study of two hundred thin sections, and forty polished surfaces. In view of the complexity of the problems presented, the lack of general agreement regarding the precise nature of the processes which deposit ores and alter rocks, and the difficulty of interpretation of the textures revealed by the microscope, the attempt has been made to present the data in an objective manner, without stressing the theoretical aspects. The discussion of hypotheses as to the genesis of the ores is reserved for the last chapter.
II
GEOLOGICAL FORMATIONS

The stratified rocks in the Taylorsville region consist in large part of ancient igneous flows and detrital igneous material, the original characters of which have been obscured by metamorphism. Diller\(^1\) has divided the series into formations on the basis of their lithological and structural characters, and has classified them by the scanty faunal remains which have been found in them in places. Those formations which originally consisted in part of andesitic flows he designates "meta-andesites". In the Mt.Ingalls district, and to the south, the stratified character of these old igneous rocks is not so clear, and Turner\(^2\) applied the name "porphyrites" to them; thus the "meta-rhyolite" of Diller is the same as the "quartz-porphyry" of Turner, and the "augite-porphyrite" of Turner is described by Diller as the "Taylor meta-andesite" of the Taylorsville region. Many of the formations of the Taylorsville region are lacking in the Mt.Ingalls district; there occur only eleven stratified formations, and five distinguishable igneous rocks, ranging in age from pre-Silurian to Recent.

It will be convenient to discuss the sediments and the older igneous rocks together.
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PRE-SILURIAN META-RHYOLITE
(Quartz Porphyry)

The pre-Silurian meta-rhyolite, described and mapped by Diller in the Taylorsville region, occurs in the Mt. Ingalls district in one locality on Little Grizzly Creek north of the Fortieth Parallel. The formation is described as a complex of surface flows, some of which are thoroughly brecciated, intermingled with much ejected fragmental material. It is a massive gray siliceous rock, generally containing phenocrysts of quartz or feldspar in a fine compact groundmass. Much of this rock has a schistose structure. The included fragments in places are rounded or angular, and sometimes amygdaloidal. Weathering gives prominence to the brecciated character of the rock. Diller considered that the flows assigned to this formation might not all be of the same age, but their separation was impracticable. The Grizzly quartzite, of Silurian age, rests on this ancient rhyolite in the Taylorsville region.

In the Downieville folio the extension of this meta-rhyolite belt is described by Turner, under the name "quartz porphyry", as a series of rhyolitic flows. He considered the dense groundmass of these rocks to have resulted in part from the devitrification of originally glassy bases.
CARBONIFEROUS FORMATIONS.

The greater part of the stratified rocks of the Mt. Ingalls district are of Carboniferous age. They were assigned by Turner to the "Bedrock Series" of the Gold Belt; he divided them into the Robinson and Calaveras formations, and the augite-porphyrite. Diller, in his work in the region immediately to the north, subdivided the Calaveras group into a number of formations, and differentiated from the Robinson a series of beds which had been assigned to that formation by Turner.

Calaveras Group.

Taylor meta-andesite.

General description.

The Taylor meta-andesite of this district is a prevailingly greenish rock of several types, corresponding closely with those of the region to the north. On the east side of Little Grizzly Creek it occurs as a massive non-schistose medium-grained rock of dark green color, which is hard and tough under the hammer. Under the microscope it is seen to have been an augite-andesite porphyry. The augite phenocrysts are now almost entirely altered to uralite; the feldspars are sericitised, and penetrated by abundant acicular actinolite. The groundmass is an extremely dense mat of actinolite and sericite.
with disseminated magnetite. In places the amount of feldspar increases, and white feldspathic phenocrysts are seen in the hand specimen; these are now composed chiefly of brushy sericite and fine epidote. In some thin sections there is an abundance of a green pleochroic biotite, pseudomorphic after augite in aggregates of small grains, occasionally brushy.

Much of this rock has been rendered schistose, and there are all transitions between the hard massive variety and a soft grayish-green schist, which appears under the microscope as an aggregate of actinolite fibers with disseminated magnetite. The latter form appears on the margins of the mass, and may represent an original marginal facies.

**Occurrence and Structure.**

The strike of the Taylor belt is roughly north and south and the dip steep to the west, as inferred from the course of the contacts on the topographic surface. The Peale and Robinson sediments lie on either side and have similar dip and strike. The schistose structure of all are parallel to the bedding. In discussing these facts Diller considered that this belt was younger than the Peale and older than the Robinson beds, on the view that the green augite-porphyrite was a flow-rock; the flows of Taylor Peak are however stated to be
older than the Peale beds. The structure and relationship of the augite porphyrite belt to the adjacent beds is therefore doubtful. It may be intrusive, or it may be older than the Peale and Robinson beds, and owe its present appearance to having been folded and compressed.

The augite-porphyrites of the Downieville quadrangle were considered by Turner to be in part of Juratrias age, but their age was in general not determined.

The thickness of the formation in the Mt. Ingalls district is not less than two thousand feet.

**Peale Formation.**

**General Description.**

The Peale beds are well exposed on the ditch near the Little Grizzly Creek - Genesee divide, and on Little Grizzly Creek near Curtner's dam. These were the only occurrences visited. They here consist chiefly of gray and black shales weathering reddish, with well-developed cleavage. Thin bedded fine-grained sandstone occasionally occurs. Chert reefs feet in thickness are notable on the west side of this area. They have vertical dip, and produce prominent outcrops on the hillside. The age of these beds is stated by Diller, on fossil evidence, to be upper Carboniferous, but lower in the series than the Robinson formation.
Distribution and thickness.

The Peale outcrops mapped by Diller south of Genesee continue southward and cross Little Grizzly Creek in two belts separated by outcrops of meta-andesite. The thickness of the formation may be as much as two thousand feet.

Relation to other formations.

The Peale belt is surrounded by igneous rocks, and its structure is doubtful. The lithology of the Peale beds is much like that of the beds assigned to the Robinson, and it is not unlikely that their horizons overlap to some extent.

Robinson formation.

General description.

The Robinson formation in the Mt. Ingalls district consists of a series of fine conglomerates, sandstones, and shales, with some calcareous lenses. The rocks are schistose and in part indurated, and on the south are changed in part to hornfels by the abutting intrusives.

The basal beds against the Taylor meta-andesite were observed above the Five Bears mine to consist of thinly laminated shale and thin-bedded fine gray sandstone, all weathering brown. A further section is exposed on the ridge between McGill Gulch and Ward Creek. It consists of a grayish-green medium-grained sandstone
containing much angular feldspar and a few sub-angular pebbles of a lighter-colored rock with greenish spots. There are a few conglomerate lenses in this section. Above these beds lies the shale horizon a (Map 2), of black thinly laminated shale weathering brown. This horizon is about twenty feet thick. On the South Branch of Ward Creek a further section is exposed. Above the shale a lies several hundred feet of an extremely hard dark gray to reddish fine-grained sandstone weathering brown. It fractures across the grains, the cleavage faces of which give the fresh fracture a spangled appearance.

Under the microscope it is seen that this rock was originally an arkose sandstone with sub-angular grains. Some of the quartz grains remain unchanged. The mass of the rock is now an aggregate of very fine ragged shapes of a colorless mineral which may be chloritoid. There are many rough prisms and sheaf-like groupings of this mineral. The groundmass contains much fine magnetite, which also occurs in the metamorphic mineral, sometimes in hour-glass arrangement.

Above this sandstone lies 70 ft. of red slaty shale, gray to black in places, overlain by about a hundred feet of the same hard sandstone and 20 ft. of black slaty shale. Above this again there is a series of hardened gray fine conglomerate and graywacke, the structure of which has been obscured by silification and recrystallisation. This series appears to lie uncon-
formably on the well bedded Robinson series and is probably to be assigned in a large part to a younger formation.

The sections of Robinson beds exposed in various places vary considerably from the section here given, due to lenticularity of the beds and the unconformable relations to other formations. On South Branch of Ward Creek, for instance, there are fifty to a hundred feet of well-bedded coarse to fine conglomerate, with well-rounded pebbles of chert or fine quartzite, above the shale horizon \( c \). This conglomerate has limited length on the strike, and gives place to the fine schistose conglomerates and graywackes before mentioned. South of the Middle Branch of Ward Creek, on the slopes of the divide to the west, some hundreds of feet of fine gray indurated pseudo-porphyritic sandstone lie below the horizon \( a \), changing to little-altered fine gray sandstone on the crest of the ridge to the south. At the base of this sandstone on the ridge are fairly coarse conglomerates which do not occur elsewhere.

The block of altered sediments surrounded by igneous rocks at the Highland Boy mine is provisionally assigned to the Robinson formation. Its proximity to the Taylor formation, together with its former calcareous content, suggest this assignment. The basal beds are of dense gray indurated sandstone, overlain successively
by a bed of brown shale, more sandstone and two calcareous horizons five to ten feet thick, separated by a pseudo-porphyrhythic fine conglomerate. These calcareous horizons are now represented by reefs of garnet and other silicates produced by the local granodiorite intrusion. The upper half of this sedimentary block consists of dense grey indurated sandstone and beds of pseudo-porphyrhythic fine conglomerate.

Under the microscope these rocks show a variety of minerals. The garnet reefs are composed in large part of brownish to greenish garnet, normal epidote, and an interstitial silicate which may be cordierite. Grains of quartz, grains and short prisms of diopside, acicular forms of actinolite, and magnetite grains, are scattered throughout. The rock is evidently a contact-metamorphosed calcareous sediment and has suffered little alteration since the recrystallisation.

The apparent phenocrysts of the pseudo-porphyrhythic material consist of the outlines of former angular and sub-angular feldspars, now occupied by a mosaic of quartz and plagioclase grains, in which are embedded a few small forms of epidote, biotite and apatite. The groundmass is a mosaic of dense quartz and plagioclase crowded with small forms of epidote, biotite, chlorite, magnetite, and yellowish-green garnet. Locally the rocks contain abundant apatite in small prisms. The micas grade from normal biotite to green
biotite and chlorite, on the one hand, and to pale brown biotite and colorless mica on the other hand; these are often grown together in parallel position. These rocks are derived either from igneous flows or more probably from coarse arkose sediments of igneous detritus. They are well bedded. There has been a little alteration since the recrystallisation, as evidenced by the presence of chlorite; but the feldspars are almost entirely fresh.

West of the South Branch of Ward Creek, and east of the divide between that stream and Little Grizzly Creek, there occurs an isolated block of dense dark gray limestone, weathering light gray, and etched by weathering on the outcrop. It is thin-bedded, and contains few fossils, except for one or two thin beds containing fragments of shells. Under the microscope this rock is seen to consist in part of fragments of corals, bivalve shells, and crinoid stems. This seems to be the locality from which Turner and his associates collected an upper Carboniferous fauna, including Fusulinias. The strike of these beds, however, is at right angles to that of the underlying beds, as shown by the fossiliferous strata, and their identity in age is not certain. This block is about 100 ft. long, and may be a landslide block.

A considerable portion of the sediments abutting on the granodiorite northwest and west of the
Lower Camp are of hornfels in which the original characters are obscured by the recrystallisation. This hornfels is provisionally assigned to the Robinson formation. The occurrence of a calcareous horizon at the Lena mine, and the occurrence of well-rounded pebbles in the indurated conglomerate immediately north-west of the Lower Camp, indicate lithological characters more closely allied to those of the Robinson than of other near-by formations.

Relation to adjacent formations.

The basal contact of the Robinson beds is against the Taylor meta-andesite. The dip is steep, and usually to the west, but Diller has shown that the formations in this belt are overturned and that the base of the Robinson beds is to the west. It is not certain that these westernmost beds are of different age from those mapped as Peale formation. The upper limit of the Robinson formation, south of the Fortieth Parallel, is difficult to define. All of the sediments in this district were assigned to the Robinson by Turner\(^2\). Diller\(^1\), however, showed that two other formations, the Kettle meta-andesite (Carboniferous) and the Trail formation (Lower Jurassic) lie unconformably above the Robinson in the region south of Genesee Valley and north of the Fortieth Parallel. It is not difficult to trace the approximate limits of the Kettle formation on lithological grounds, although the brush and thick soil
in places prohibit the tracing of the exact contact. Above the well-defined beds of the Robinson in sections 30, 31, and 36, there lies a thick series of poorly bedded schistose rocks which differ in dip, strike, and lithological character from the Robinson beds. To add these to the Robinson would bring the total section to well over five thousand feet in thickness, whereas in the Genessee locality Diller reports a thickness of 1150 ft. The well-bedded Robinson in the Mt. Ingalls district attains a thickness of more than 2500 ft. It therefore seems necessary to separate the poorly bedded series into another formation. This is provisionally assigned to the Trail formation of Diller. The structural position and lithological character of these beds are more analogous to those of the Trail than to those of any other formation in this region. They are, however, in large part converted into hornfels, and it is possible that they include rocks of widely different ages; the assignment of them to the Trail formation must therefore be regarded as a matter chiefly of convenience.

Age.

The section of Robinson beds near Genessee contains plentiful fossils, and the age has been determined by a number of paleontologists as Upper Carboniferous. This conclusion was also reached by Turner's associates in the study of fossils from the locality on the South Branch of Ward Creek.
Kettle Meta-andesite:

General description.

The Kettle meta-andesite in the Mt. Ingalls district consists of several types of rocks, which show some gradation. The basal portion (next the Robinson beds) consists chiefly of a massive highly-altered porphyry, with light-colored phenocrysts set in a rather soft greenish or brownish matrix with dull luster. Under the microscope it is seen to have been once a feldspathic, quartz-free, porphyritic igneous rock poor in iron. It is now entirely altered to dense sericite and clay minerals, with a small amount of secondary quartz, epidote, calcite and magnetite. Some of the rock above this phase is apparently of the same type but has been rendered schistose and of obscure structure. There occurs in this series a consistent indurated slaty shale or tuff bed twenty or thirty feet thick, which possesses the general strike and dip of the Robinson beds to the west. This shale is of purple color weathering chocolate-colored, and locally shows green spots. Under the microscope it shows clastic quartz grains and "augen" of sericite and clastic quartz arranged in a very dense schistose matrix apparently of sericite or clay minerals. The quartz has strong wavy extinction. Above the shale the Kettle consists largely of soft light-colored much-altered tuffaceous or effusive material. Outcrops are rare in this area, due to the softness of the material.
The ridges composed of this rock can be distinguished at a distance by the light-colored soil and somewhat sparse vegetation.

**Occurrence.**

Diller states that the Kettle is composed of a series of flows and tuffs laid down over the Robinson beds. The nature of the Ward Creek contact suggests that uplift and erosion of at least a thousand feet of these beds preceded the deposition of the Kettle over the Robinson. This view is supported by the essential parallelism of the Kettle tuff to the bedding of the Robinson. However it is not unlikely that some part of the basal mass on Ward Creek may be intrusive.

**Distribution and Thickness.**

The Kettle belt extends only a few thousand feet south of the Fortieth Parallel. It occupies the east bank of the canyon of Ward Creek proper. The thickness is difficult to estimate on account of the obscurity of the structure, but is given by Diller as at least 4000 ft.

**Age.**

Diller assigns the Kettle to the Upper Carboniferous above the Robinson beds. It would seem that a considerable interval elapsed between the deposition of the two formation.
Nix Porphyrite.

General Description.

This porphyrite is a dark greenish rock crowded with white feldspar phenocrysts. These phenocrysts are up to 2 cm. in length and are commonly of elongated form with steplike terminations. On weathered surfaces the phenocrysts are conspicuous and the rock assumes a light gray color. In places alteration has reduced the porphyrite to a soft light-colored rock of indistinct structure. Fine-grained epidote is visible in many hand specimens.

Under the microscope the rock is seen to have been heavily altered. The phenocrysts are of plagioclase, now sheared, sericitised, and silicified. The groundmass consists of a very dense mosaic of quartz, biotite, and magnetite. Epidote occurs, and grains of yellowish-green garnet and laths of white mica are not uncommon. Small veinlets of quartz traverse the rock, and scanty grains of bornite and possibly chalcocite are somewhat generally distributed among the alteration minerals. There is no visible primary quartz, and it is probable that the rock was originally of andesitic composition.

The alteration of this rock is of contact metamorphic type, and is probably due to the effect of the nearby granodiorite intrusion. In some places, not-
ably on the contact with the McGill porphyrite, there has been alteration of a type associated with the formation of quartz veinlets, and characterised by the development of coarse epidote.

**Occurrence and relation to other formations.**

The Nix porphyrite occurs as an irregular mass between the Taylor meta-andesite and the Robinson hornfels, in the neighborhood of the Highland Boy mine. It partially envelops the block of sediments at that mine, and is bounded on the north by the McGill porphyrite and on the south by the granodiorite. It contains no sedimentary horizons, and shows no bedded structure. It is probably an intrusive mass. In lithology it differs notably from the McGill porphyrite, and must be described as a separate rock. It is impossible to correlate it with certainty with any of the other intrusives in this region, and is here designated the "Nix porphyrite" for convenience.

A small outcrop of a rock of similar character occurs on the ridge between McGill Gulch and South Branch of Ward Creek. It lies between the Robinson Shale and the McGill porphyrite, and is probably to be assigned to the Nix porphyrite.

**Age.**

The Nix porphyrite is older than the gran-
odiorite and younger than the Robinson formation. It may be older than the McGill porphyrite. The age is thus between the Upper Carboniferous and the Lower Cretaceous. It closely resembles in petrographic characters the Reeve andesite described by Diller, which intrudes the Robinson beds in the neighborhood of Genesee, and to which Diller assigns a late Carboniferous age. The Mix porphyrite may therefore be as old as the Carboniferous.
JURASSIC FORMATIONS.

Trail formation.

General description.

The beds mapped as belonging to the Trail formation in the Mt. Ingalls district, south of the Fortieth parallel, consist of three types. Immediately above the Robinson lies about 300-500 ft. of indurated conglomerate, with a gray matrix containing pebbles of gneissoid and schistose rocks up to 3 inches in diameter. The outlines of the pebbles are indistinct in the fresh fracture, but on weathering the rock forms characteristic light-colored boulders on which the pebbles stand out in relief. There are abundant irregular light green patches, which stand out in relief on weathered surfaces. This series of beds shows considerable variation in the size of the pebbles; some beds appear locally as coarse graywackes or poorly sorted conglomerates with pebbles of gneissoid and schistose rocks up to 3 inches in diameter. The induration and rough schistosity of the rocks has in general obscured the textures.

Under the microscope the graywacke type is seen to have been a clastic rock, consisting of angular or sub-angular grains of quartz, fine-grained quartzite, plagioclase feldspar and apparently some potash feldspar. These grains are embedded in a matrix of much
finer grain, originally composed in part of quartz and feldspar fragments. The rock has suffered considerable alteration of hydrothermal type. The feldspar is largely altered to dense sericite, actinolite, epidote, and a little chlorite; the clastic quartz is relatively unchanged, but is penetrated and corroded by sericite. There is abundant coarse and fine secondary magnetite in the rock, confined chiefly to the dense matrix, though occasionally occupying cracks and zones in the feldspar. There has been complete cementation by secondary quartz. This is a clastic rock formed in part from sedimentary rock fragments, but chiefly from igneous detritus; the material has suffered very little transportation. The imperfect stratification of this series, and the imperfect sorting and angularity of the material, suggest that these rocks are continental deposits.

Above this series lies a massive medium grained indurated gray rock with the appearance of sandstone, containing occasional spots which may once have been pebbles. Bedding is indistinct or absent, and the structure is obscured by the dense vegetation and the mantle of detrital soil which covers the outcrops. There are occasional small green patches in these rocks. The thickness of this series is from 600-1200 feet.

Under the microscope this rock is seen to
consist of laths or cleavage fragments of feldspar with albite twinning, arranged with a strong tendency to parallelism; they are separated, corroded and penetrated by abundant epidote and acicular actinolite, associated with apparently secondary magnetite and some chlorite. This rock is either a metamorphosed effusive igneous rock, such as a "spilite" basalt, or an altered sediment composed of igneous detritus which has not been transported far. Regional or contact metamorphism has altered the original dark minerals to epidote and actinolite, with production of secondary magnetite. The alteration is of hydrothermal type.

The green spots so common in the altered rocks in this neighborhood appear under the microscope to consist of dense irregular epidote embedded in a dense mosaic of anhedral quartz grains which forms from 10\% to 50\% of the mass.

Above this gray sandstone-like rock there lies a considerable thickness of knotty and schistose rocks which have suffered considerable recrystallisation caused by the underlying granodiorite intrusive. The structure is obscure, but the total thickness exposed may exceed 2000 ft. These rocks have a considerable content of iron minerals, and weather to reddish brown outcrops which are sometimes fairly soft. The fracture sometimes shows a silky appearance. There are abundant
knots which form "augen" in the schistose structure, and green irregular epidote patches are common. Some of these rocks appear to have once been of conglomeratic type, but the pebbles are now more or less merged in the altered mass.

Under the microscope a specimen is seen to have once been a clastic rock formed of angular fragments of plagioclase embedded in a finer-grained matrix. The feldspar grains are now almost entirely changed to dense recrystallised mosaic of quartz, in which are embedded laths of biotite and less plentiful colorless mica. Epidote occurs in irregular grains, and chlorite is plentiful, usually in pseudomorphs after or intergrown with biotite. Magnetite is disseminated throughout. There are occasional areas of coarser anhedral quartz which locally have the character of veinlets. This appears to have been a sediment formed of igneous debris which suffered little transportation. The partial recrystallisation may be due to contact metamorphism.

On the eastern edge of the exposure of this formation south of the Fortieth Parallel the metamorphism is associated with the process as of ore-deposition which formed the Walker Mine copper deposits. This phase is described in connection with the Walker mine deposits. Relation to other Formations.

The Trail formation mapped by Diller in the
area south of Genessee Valley does not connect southward with the formations just described south of the Fortieth Parallel; the two areas are separated by the Kettle outcrops and by the overlying basalt sheet. No definite connection can therefore be traced; but the structural position and lithological characters suggest the provisional correlation of the two areas. In the southern area the beds appear to lie unconformably against the Robinson; dips and strikes measured on the best available bedding planes are markedly different in the two series, and the contact has a strong curvature inconsistent with the attitude of the Robinson beds. The attitude of the Trail series, however, is not certainly known, owing to the poor definition of the bedding; some of the observed planes may be planes of schistosity. It is certain that the schistosity directions of the Trail series in this area differ from those of the Robinson beds. It seems probable that the Trail series dips 50°-70° to the east, and overlaps the vertical Robinson beds.

The Trail formation in this area terminates abruptly against the Kettle series to the west of Grouse-tree Camp. The character of this contact could not be determined on account of the vegetation in this locality. Such abrupt transitions occur also in the area north of the Fortieth Parallel as mapped by Diller, and may be due to the faulting of unconformable contacts.
On the east the Trail series south of the Fortieth Parallel is overlain by the Mt. Ingalls basalt sheet. The strip of hornfels northwest of the Lower Camp may contain some rocks belonging to the Trail formation, but it was not possible to separate them from those of the Robinson formation.

**Age.**

The Trail formation of the Taylorsville region is assigned by Diller to the Lower Jurassic; it is a land or freshwater formation, and contains very few fossils; near Genesee it overlies the Triassic and is overlain by marine sandstone containing Lower or Middle Jurassic faunas.

**Hull meta-andesite.**

In the Taylorsville region Diller has described and mapped under the term "Hull meta-andesite" a series of sediments and andesitic flows which he considers to be of Lower Jurassic age. It forms a part of the hills east of Little Grizzly Creek immediately south of Genessee Valley. This locality is rugged and densely wooded, and little information was obtained concerning this formation. The contact with the Peale formation crosses Little Grizzly Creek immediately south of the Fortieth parallel.

A thin section from the formation at this
locality contains short phenocrysts of feldspar up to 5mm. in length, both as single crystals and in groups of a few individuals. These are scattered through a dense groundmass composed chiefly of laths of feldspar in random arrangement. The feldspars appear to be in large part of potash feldspar, with some sodic plagioclase. Primary quartz or femic phenocrysts are scarce or absent. This rock was originally a quartz-free acid prophyry, composed almost entirely of feldspar, and may have been a trachytic effusive. It is now considerably altered and the characters are somewhat obscured. The feldspars are corroded and embayed by fine chlorite and epidote which have replaced the original interstitial matter, and are clouded by sericite and epidote.

McGill Porphyrite.

General Description.

This porphyrite is a dark gray rock containing small equidimensional, usually square, phenocrysts of feldspar in a dense groundmass. Elongated phenocrysts are rare. The feldspars are conspicuous on a weathered surface, and the rock weathers to a lighter gray color. In the vicinity of McGill's Tunnel the phenocrysts are locally smaller, and the rock is distinctly vesicular. Some of these vesicles have been partly filled by secondary minerals which weather out as white rings.
Under the microscope the typical porphyrite is seen to be a much-altered rock, in which however the original characters may still be distinguished. The feldspar phenocrysts are embedded in a dense groundmass of fine feldspar laths with distinct flow structure. Much of the feldspar appears to have been potash feldspar, and the remainder a solid plagioclase. Fresh apatite prisms and magnetite grains are plentiful. The interstitial matter has been partly recrystallised with the formation of very fine forms of biotite and secondary quartz. Further alteration has produced fine epidote and chlorite. The phenocrysts are in general little altered, except for clouding by sericite and fine epidote; however, biotite laths have developed in a few phenocrysts, and a few are sheared and traversed by biotite and quartz.

A section of amygdaloidal porphyrite from the spur north of McGill's Tunnel shows a higher degree of alteration associated with processes of ore-deposition. A small amount of bornite is locally developed, and the presence of tourmaline is characteristic. This alteration is described in the section of ore-deposits.

**Age and Relation to other Formations.**

The McGill porphyrite lies between the Taylor meta-andesite and the Robinson formation, and adjoins
the Nix porphyrite on the south. It is younger than the Robinson formation and older than the Granodiorite intrusion. Its locally vesicular character indicates its origin as an effusive rock. The petrographic characters are very similar to those of a part of the Hull meta-andesite of Lower Jurassic age. The age of this porphyrite is certainly between the Upper Carboniferous and the Lower Cretaceous. It probably belongs to one of the Lower Mesozoic series of effusive rocks which are well exposed in the Taylorsville region.
TERTIARY AURIFEROUS GRAVEL.

In the Downieville quadrangle and in the Taylorsville region there occur extensive deposits of auriferous gravels, the sequence of which has been worked out by Turner$^1$ and Diller$^2$. During the Tertiary this region was a land area on which a great river flowed from the south to the north, having its headwaters far to the south and debouching into a lake or estuary in the neighborhood of Diamond Peak, south of Susanville. This was the "Jura River" of Turner and Diller, and its former valley is marked by remnants of gravel beds carrying some gold. The Diamond Peak section is several hundred feet thick, and the lower strata contains Eocene plant remains. These Eocene beds are lacking in the Mt. Ingalls district, but a number of areas of gravel occur, which Turner has assigned to the Neocene. These gravels are of well-rounded pebbles and small boulders, and are readily recognised by the composition of the pebbles. These often consist of coarse-grained acid igneous rocks which do not occur in place anywhere in the vicinity. White quartz pebbles are less common. The outcrops are inconspicuous, but the float pebbles are unmistakeable. The pebbles are weathered and shatter under the hammer. Hydraulic mining operations have exposed sections of the gravel on the west bank of Little Grizzly Creek.
QUATERNARY ALLUVIUM.

Recent gravels occupy small areas in the Mt. Ingalls district. The Genessee Valley is a gravel-filled flat valley encircled by abrupt slopes; much of its filling consists of detritus from the Mt. Ingalls region. The relatively insignificant creek gravels of Little Grizzly Creek are of economic interest below the Tertiary gravel beds on the hill-sides; the gold content from the erosion of the old gravels has been to some extent concentrated in the creek bed. The gravels of the side creeks have also been the object of prospecting operations.
IGNEOUS ROCKS.

Granodiorite.

A considerable part of the Taylorsville region and the Mt. Ingalls district is underlain by plutonic rocks, which reach the surface in numerous large and small areas. This underlying mass is part of the northern extremity of the great batholith of the Sierra Nevada, although on the surface the general continuity of the intrusive masses is obscured by the overlying sediments and effusive rocks. On the western slopes of Mt. Ingalls five areas of outcropping plutonic rocks are mapped. It is probable that these areas are not merely apophyses of an underlying uniform mass, but are to some extent separate intrusive bodies. The structure of the Mt. Ingalls district is probably to be considered as a complex of small intrusives injected into the superjacent sediments from an underlying deep-seated reservoir. Erosion has laid bare a cross-section of a part of this structure, but much of it is now covered by later effusive flows. Some of the intrusives mapped are almost certainly continuous with each other under the lava cap. Little is known of the relative ages of the plutonic exposures; but they are thought to belong to the same general epoch of intrusion. Rocks of granodiorite composition are common in
the Taylorsville region, but in the Mt. Ingalls district
the composition is generally that of quartz diorites.
In the intrusive masses themselves there has been notable
further differentiation, with the production of pegmatites
and aplites; and a variety of metamorphic rocks has been
produced on the contacts with the sediments. Among these
are some of the copper-deposits of this district.

General Description.

In the field the granodiorite intrusive rocks
appear as medium-grained quartz-feldspar rocks with a
small percentage of dark minerals. In the larger masses
black biotite crystals are well developed, but in many
places they are inconspicuous; the hand-lens generally
reveals the presence of small amounts of hornblende. The
outcrops are heavily weathered, and are in general cover-
ed by vegetation and a mantle of detritus. The occasion-
 al boulders and outcrops are rounded and somewhat friable.

The mass south of the Lena mine contains well-
developed biotite crystals and abundant basic secretions
of darker color and finer grain than the rest of the
rock. These secretions are from an inch to six inches
in diameter and of rounded outline. Under the microscope
the normal rock is seen to consist of about 40% quartz,
40% plagioclase feldspar, 10% biotite, and 5% hornblende,
with tourmaline, apatite, titanite, zircon, and scanty
magnetite as accessories. The quartz is interstitial in character, contains abundant minute fluid inclusions with mobile gas bubbles, and shows anomalous extinction (fig. 4, Plate IX). The feldspar is in idiomorphic forms with marked zonal structure, consisting generally of andesine in the centers grading into oligoclase on the borders of the crystals. Pericline twinning is often combined with the common albite type. The biotite and hornblende are of the common varieties, in medium-sized single grains, sometimes with ragged outlines. The tourmaline is brown and pleochroic and occurs in ragged forms. The apatite and zircon present the usual idiomorphic appearance.

The titanite and magnetite are in rough grains, occasionally in crystals.

The basic secretions (fig. 1, Plate IX) consist of fine even-grained aggregates of hornblende, biotite, plagioclase feldspar, and a little quartz; the proportions are approximately 20% biotite, 20% hornblende, 40% feldspar, and 10% quartz. The accessory minerals apatite, magnetite, titanite, zircon, and tourmaline are conspicuous and well-developed. The minerals are identical with those of the normal rock.

These rocks have suffered some hydrothermal alteration. The biotite and hornblende are in part changed to chlorite in parallel position. Fine sericite, chlorite,
calcite and epidote cloud the feldspar, especially along cleavage and twinning planes and in the zonal markings of zoned crystals.

A thin section from the exposure on the ridge between Little Grizzly Creek and South Branch of Ward Creek presents a different appearance. The rock is medium-grained and contains about 30% quartz, 30% plagioclase feldspar, 20% hornblende and 10% biotite. The quartz is of interstitial character, with abundant and minute fluid inclusions with mobile gas bubbles, and shows anomalous extinction. The feldspar is andesine, with rather broad albite lamellae, and usually occurs in zoned crystals. Inclusions of small idiomorphic crystals of apatite, titanite, hornblende, and biotite are common in the zoned andesive crystals. The hornblende and biotite are of the common varieties; they occur partly as separate crystals embedded in quartz, and partly in aggregates containing dendritic arrangements of fine magnetite (fig. 2, Plate IX). The separate hornblende crystals are often twins, and occasionally contain areas of pale-colored augite in parallel position. Other occurrences, of chlorite surrounding as of fibrous amphibole in parallel position, or in brushy arrangement, may be due to hydrothermal alteration of augite with "magmatic resorption" border of hornblende (fig. 3, Plate IX). Titanite, apatite, and zircon are accessory minerals. There has been some hydrothermal alteration of this
rock; chlorite is in part pseudomorphous after biotite and hornblende, and the feldspars are penetrated and clouded by fine sericite and minerals of the epidote group.

The peculiar texture of this rock may indicate its occurrence as an intrusive of small dimensions or as a marginal facies.

The character of the rocks composing the various other exposures was not studied in detail. There occurs two other types of plutonic rocks in the underground workings of Walker mine, which probably constitute the exposures near the Upper and Lower Camps. These were not studied on the surface, and are described in the section on Walker mine.

**Pegmatite and Aplites.**

The plutonic rocks of the granodiorite group in the Mt. Ingalls region contain numerous acid dikes, usually of small size, which are especially abundant near the periphery of the masses. Three-fourths of a mile south-east of the Lower Camp there occurs an exposure of pegmatite which projects through the thin basalt sheet at that place. This pegmatite consists almost entirely of a fine-textured graphic intergrowth of quartz and microcline. Under the microscope it appears that the microcline constitutes a little more than half of the rock. There are small amounts of sodic plagioclase, biotite, apatite, and tourmaline. There has been
some hydrothermal alteration.

Near the Highland Boy mine there occur small fine-grained aplite dikes. These appear in this section to consist almost entirely of quartz and plagioclase feldspar with a little microcline. Aplitic intergrowths are well developed in this rock.

A variety of small pegmatitic and aplite dikes, rich in quartz, are exposed in the workings of the Lena mine; and similar rocks occur in the plutonic rocks in the Walker mine. These are described in the sections on those mines.

On the margins of the granodiorite exposures local segregation gives rise to a variety of igneous rocks of small extent and irregular distribution. These are not well exposed in the Mt. Ingalls district, owing to the weathering of the granitic rocks, but a variety of types occurs in float in the neighborhood of the contacts.

A hundred feet west of the cookhouse at the Lower Camp, on the north bank of the creek, there is an outcrop of hornfels which is locally altered to a rock resembling greisen. This occurrence is only a few feet distant from the quartz diorite contact. In this section this rock is seen to have been a coarse-grained aggregate of quartz and colorless mica, with minor amounts of biotite and idiomorphic feldspar. Later
alteration has developed much dense sericite, which
corrodes and penetrates the quartz and occupies the old
feldspar outlines. The biotite is now chlorite. The
quartz has anomalous extinction, and contains very numer-
ous and unusually large fluid inclusions with mobile gas
bubbles. Some apatite and tourmaline is present. This
rock is traversed by irregular veinlets of coarse anhedral
quartz, containing abundant iron tourmaline in prisms and
"suns", and subordinate colorless mica.

Age.

The intrusives grouped under the name of
"granodiorite" in this region intrude and metamorphose
all the sediments older than the Tertiary; the Cretaceous
and Upper Jurassic horizons are however absent in this
region. Turner and Diller assigned these intrusives
to the Upper Jurassic or Lower Cretaceous, the great
period of granodiorite intrusions in the Sierra Nevada.

Curtner quartz-diorite porphyry.

General description.

This is a dense dark gray rock containing
a few small phenocrysts of quartz and plagioclase feld-
spar, up to 1 mm. in diameter. In thin section these are
seen to be embedded in a dense complex of fine feldspar
laths and perhaps some quartz. The feldspar is oligo-
clase-andesine. Apatite needles and fine magnetite grains
are plentiful. There has been some hydrothermal alter-
ation; fine forms of epidote are plentiful in the groundmass, and some chlorite is developed. The feldspars are somewhat cloudy and contain fine forms of epidote. In the groundmass occur aggregates of coarser epidote and chlorite, with associated magnetite, which may represent original ferromagnesian silicates.

Occurrence.

The Curtner quartz-diorite occurs as a dike in the Taylor meta-andesite, crossing Little Grizzly Creek below Curtner's placer mine. This dike is weathered out as a wall 4 - 10 ft. wide at that place. It was not traced over the crest of the ridge east of Little Grizzly Creek. The contact with the Taylor is marked by little metamorphism; a few inches of indurated rock have been produced. The massive Taylor porphyrite a few hundred feet above the creek is jointed by regular and persistent joint-planes normal to the plane of the dike. These planes are now occupied by a filling composed of coarse epidote prisms transverse to the fissures, embedded in a structureless light-colored matrix. These epidote fillings are rarely more than a few inches in width, tend thirty or forty feet away from the dike. Inspection of these features suggests that the dike was intruded into a fault in the Taylor meta-andesite and the solutions emanating from the dike altered the gouge in the associated joints to epidote.
Age.

The age of this occurrence is not certainly known. It is probably younger than the granodiorite. Its dense holocrystalline character shows that it was intruded at moderate depth, and the physiographic history of the region shows that the indicated conditions obtained during the earliest Tertiary or later Mezozoic.

Black Basalt

General description.

This is a black dense, vesicular, or amygdaloidal basalt with occasional olivine grains in a dense or glassy base. The fracture is conchoidal, and the arrangement of the flows conforms in large degree to the present topography. The outcrops usually weather to heaps of small brown boulders up to 6" in diameter, though occasional relatively unaltered outcrops occur. Under the microscope a typical specimen is seen to consist of about 20% olivine, 40% augite, and 30% bytownite feldspar. The augite is pale green and occurs partly as phenocrysts and partly in the groundmass. The groundmass is of very small augite prisms and clear laths of bytownite in a brown base, with ophitic texture. Magnetite is abundantly disseminated through the rock.

Relation to other formations.

This black basalt occurs in the Mt. Ingalls district as remnants of flows on the lower spurs of Mt. Ingalls. In the Downieville folio Turner classified
a series of black basalts as the "older basalt", which he assigned to the middle Tertiary, and which he regarded as older than the gray basalt. In the Mt. Ingalls district it is not clear whether the black basalt underlies the gray basalt sheet, and outcrops on the edges, or whether it belongs to later flows which have been eroded from the higher slopes. It is clearly older than the volcanic agglomerate with which it is intimately associated.

**Gray Basalt.**

**General description.**

This is a light gray rock containing visible small olivine and augite phenocrysts in a dense groundmass. Weathered surfaces are gray or brown. The structure in the field is usually massive, but occasionally the rock has a laminated structure, due apparently to shrinkage cracking.

Under the microscope a typical specimen is seen to consist of about 10% olivine, 30% augite, and 40% plagioclase feldspar. Small phenocrysts of olivine and augite are embedded in a fine-grained groundmass of small augite prisms and feldspar laths in an ultimate base of brown glass. The augite occurs often as a fringe around olivine, as well as in separate crystals. The feldspar is apparently bytownite, and has broad albite twinning. The texture of the rock is ophitic; the groundmass feldspar laths are bent around the pheno-
crysts. The augite, olivine, and feldspar have zonal inclusions of brown glass. Nodules of dense even-grained aggregates of olivine, augite, and feldspar occur and may represent an earlier crystallisation. Apatite and magnetite are accessories.

A specimen from the Ward Creek-Little Grizzly Creek ridge shows a different type. This is a gray dense rock without apparent phenocrysts. Under the microscope it is seen to consist of about 60% plagioclase (anorthite or bytownite) and 30% augite with little or no olivine. Small crystals of feldspar and a few of augite are embedded in a dense base composed of very small augite and feldspar crystals in brown glass. The groundmass augite prisms frequently project into the larger feldspar crystals. Rounded and annular forms of brown glass crowded with magnetite dust are common. Grains of magnetite and fine apatite needles are present as accessories.

Occurrence:

This gray basalt occurs as extensive thick flows which cap Mt. Ingalls and cover much of its upper slopes. The total thickness may exceed 1000 ft. and the area covered is more than ten square miles.

Age:

This basalt is assigned to the Neocene by Turner and Diller, on the basis of its relations to the
suriferous gravel series. The lava cap of Mt. Ingalls is built up of a series of flows, and its formation may have occupied a considerable duration of time during the upper Tertiary.

**Agglomerate.**

**General description.**

This volcanic rock is an aggregate of rounded boulders, brecciated fragments, and explosion material of angular form embedded in a finer matrix. Most of these fragments are vesicular or amygdaloidal, and vary in color from gray to blue, red, brown and black. The amygdules are often colored bluish and reddish. Porphyritic texture can be distinguished in a few of the fragments on fresh fracture, but much of the material resembles cinders or clinker. This rock is fairly well cemented, and erodes into reef-like masses or isolated monuments; where massive it forms cliffs (fig. 3, Plate VII).

Specimens from near Lovejoy's show strongly basic composition of the pebbles, boulders, and matrix. The composition probably varies within wide limits.

**Occurrence.**

This agglomerate occurs as sheets on the lower spurs of Mt. Ingalls west and south of the Lower Camp. It occupies a large area to the south, and extends over to Clover Creek. This exposure was classified by Turner as "Andesite, in part fragmental"; he considered the age
intermediate between that of the "older basalt" and the gray basalt. It is probable that this complex is of widely different ages. The crest of Mt. Ingalls, south of the highest point, is strewn with cindery volcanic material which may have been blown out of vents in the vicinity. It is not unlikely that the agglomerate north of Lovejoys is of later age than the andesitic mass to the south and east.
STRUCTURAL GEOLOGY.

The Peale, Taylor and Robinson formations, of Paleozoic age, form a monoclinal series striking a few degrees west of north and dipping steeply to the west. The dip of the Peale beds averages 60°-70° W, and that of the Robinson is nearly vertical. This monoclinal arrangement is probably due to compression of earlier folded structures containing intrusive sheets. On the west the Hull meta-andesite occurs partly as unconformable sheets and sediments and partly as a large sill in the Peale formation. On the west the Kettle meta-andesite lies disconformably against the Robinson. The Trail formation probably lies unconformably on the Robinson and Kettle with a dip of 30°-60° E. The schistosity of all these formations is roughly parallel to the bedding.

The granodiorite batholith underlies the whole region and sends small intrusive masses or apophyses into the superjacent sediments.

Some evidence was found of the existence of a few strong nearly vertical faults striking approximately north-west. Such faults are well exposed at the Gruss mine and at the Grizzly prospect. The Curtner dike possesses this dip and strike, and may have been injected into a
fault fissure. These faults in no case appear to dislocate the steeply dipping monoclinal beds on the strike; but the contacts of the flatter lying Kettle and Trail formations show abrupt dislocations which have roughly northwest strike. The contacts of the Neocene basalts are undisturbed by such dislocations. It therefore appears probable that the district is traversed by strong faults, with roughly northwest strike, steep dip, and approximately vertical displacement, and that these faults are of early Tertiary or late Mesozoic age.

The auriferous gravels are more or less horizontally bedded, and rest unconformably on the pre-Tertiary basement. The basalts also lie unconformably on the pre-Tertiary rocks.
IV

PHYSIOGRAPHY OF THE DISTRICT.

The Tertiary topography of this region has been described in detail by Turner and Diller. It was an undulating subdued land surface of moderate elevation across which flowed from south to north a great drainage system which has been called "Jura River", from the remains of its channel on the ridge of Mt. Jura near Genesee. This system, by repeated degrading and aggrading, washed and re-washed the detritus brought from the south and deposited it in a rather broad but not extensive valley extending across the northwest corner of the Mt. Ingalls district. Towards Susanville the river debouched into a plain or lake where it deposited great beds of sand and gravel over a wide area. In the Neocene a series of lava flows was poured out over part of the country from vents in the neighborhood of Mt. Ingalls. At the close of the Tertiary the surface was uplifted and the mature surface, which now lies at an elevation of 6000-7000 feet, was cut into by drainage systems flowing west towards the Sacramento Valley. The region is now deeply dissected by the rapidly cutting tributaries of Feather River in young V-shaped canyons. Some of the older and more extensive valleys were later filled by alluvium and perhaps occupied by lakes and now remain as Genesee and Indian Valleys. The
old subdued surface and the rather broad valley of Jura River remain in many places on the ridges above the streams. The gravel benches have an elevation of from 5600-6200 feet in this neighborhood. Mt. Ingalls was probably a hill of moderate elevation overlooking the valley of Jura River, and was built up by a series of lava flows to its present commanding height during the later Tertiary. The older Tertiary surface truncated the upturned hard and soft formations, including the Walker vein system. The outcrops were then covered by lava flows; but the Walker mineralised belt had stood out as a ridge during the early Tertiary erosion, owing to its hardness; and later erosion removed part of the basalt sheet from the outcrops.

During the Tertiary the erosion must have been rapid, for there is only a limited amount of oxidation of the Walker copper ores below the basalt cap. Since then erosion has also been rapid. The elevation and rainfall, the frosts of winter and the heat of summer produce rapid disintegration in all the rocks except the siliceous hornfels and the tough uralitised porphyry of the Taylor belt.

The glacial period left few traces in this region. Diller has described a small glacial moraine descending the steep eastward slope of the Grizzly mountains towards Genesee. This moraine presents an inter-
esting example of glacial action, as seen from the hills across the canyon. It is quite evident that the glaciers of this epoch were very small and had limited gathering ground. They were formed when the topography was almost the same as it is today, and they altered it little. The fact that the bench-gravels still remain in their exposed positions indicate the feebleness of the glacial erosion in this region.
ORE - DEPOSITS.

PLACER DEPOSITS.

The Tertiary bench gravels of the Mt. Ingalls district carry some gold, but not in channels of sufficient value to justify drift mining. The elevated position of the bench-gravels makes it difficult to secure a supply of sluicing water at low cost. At the Cascade mine, on the west bank of Little Grizzly Creek, water for hydraulicking was obtained by means of a ditch several miles long, which tapped the headwaters of a number of little creeks flowing down the steep eastern slope of the Grizzly Mountains. A fair supply of water was thus available in the spring. In 1895 the Cascade gravel bank was 150 ft. high, averaging 13 to 20 cents per cubic yard in fine gold; the water season was ninety days. The problem of disposing of debris caused the cessation of mining. Attempts were made to mine nearly all the exposures of Tertiary gravels in this district; ditches were dug on the hill-sides above the gravels to the nearest creeks. The supply of water thus obtained was limited, and was available only in the spring. The California debris disposal law finally put an end to the attempts to exploit these gravels.
The early prospectors found gold in the gravels of the present creek beds below the Tertiary gravels, and in smaller amount in the creeks traversing the older rocks. The gravels of this type are limited in extent and were for the most part worked out at an early date. In the bed of Little Grizzly Creek there still remain gravels containing gold derived from the erosion of the bench gravels on the slopes above. The Curtner mine, a mile below the Highland Boy mine, is in intermittent operation on a small stretch of creek gravel. The gold is often coarse and lies chiefly on the bedrock; large boulders occur, and the low level of the gravel relative to the creek necessitates the use of a hydraulic elevator, which in turn requires great quantities of water. There is a perennial shortage of water, and production is small. The debris is impounded by a log dam two miles down the creek.
BEDROCK DEPOSITS.

The ore-deposits of the Mt. Ingalls district lie at the southern termination of the Genesee belt, which extends from Ward Creek due north to Lights Creek. This belt is about fifteen miles long. The Engels and Superior copper deposits lie at the northern extremity. The copper ores of this belt are genetically connected with the granodiorite batholith. They may be broadly classified as vein deposits of moderate-depth type, vein deposits of deep-seated type, contact metamorphic deposits, and magmatic deposits in the intrusive itself. The representatives of the latter class are the Engels deposits. The Walker deposits are veins of deep-seated type. Between these mines, which are at present the only producers, there occur a number of exposures showing copper mineralisation. A few of these have been producers in the past, but none are producing at present.

In the older formations of the region occur some gold-quartz veins which appear to antecede the granodiorite intrusion. These occurrences are older than the copper deposits of the Genesee belt.
Older Quartz Veins.

In the Peale and Robinson formations there occur large numbers of small quartz veinlets which in almost all cases lie parallel to the bedding. They are of white quartz, often with vugs, and less often with comb structure. No metallic minerals are visible in them. A few such veinlets occur in the Taylor meta-andesite near the Peale formation, with clinochlore as a characteristic associate. These veinlets sometimes ramify in the sedimentary country rock, and occasionally appear as the cement of brecciated chert and sandstone. The best exposure of quartz veins of this type is at the Gruss Mine, on Ward Creek; here they are cut by small veinlets of later age, carrying copper.

Gruss Mine.

The Gruss mine is on Ward Creek near Genesee Valley. In 1865 gold was found in the detrital overburden and hydraulic mining operations exposed the veins. Rich gold ore was found, and the mine was operated for many years on a small scale. Mining was at first by open cuts and later by shallow shafts. The ore was treated in arrastra and later in a small stamp mill. About 1900 another company sank a shaft to the 400 ft. level to prospect for copper. Some stringer mineralisation was found but no profitable ore-deposits were developed.
The total gold production, according to R. Gruss, exceeds a million dollars.

There are two chief veins at the Gruss Mine. One is known as the main vein, and has a dip of about 30° W and strike N 10° W; it lies between gray to black shale of the Robinson formation and a spotted brown rock locally known as "porphyry". Under the microscope the latter is seen to be a dense siliceous schist, composed chiefly of quartz with strong wavy extinction. There are numerous elongated aggregates of fine biotite laths, which are in general oriented parallel to the schistosity and which give the spotty appearance. Later alteration has replaced much of the biotite with pseudomorphous chlorite, and oxidation has stained the rock with limonite and hematite.

Under the microscope the shale is seen to be composed of oriented dense sericite, of which the individual flakes are scarcely resolvable by the microscope; it contains a few detrital quartz grains in miniature augen, and some chlorite and magnetite are locally present. This rock is designated "slate" by Diller. In the hand-specimen it resembles shale. It is a dense sericite phyllite, intermediate between a shale and a sericite schist in the megascopic classification. The name "shale" is used here for convenience.
The main vein is lenticular and is up to twenty feet thick. The other vein is much smaller, and parallels the main vein some fifty feet distant on the hanging wall side. It has a dip of about 30° W in shale country rock. There are a number of stringers of similar type in the shale, some of which conform to the steep dip of the shale (fig. 1, Plate VII).

The veins are offset by a strong fault striking NW and dipping 75° NE. The offset is about a hundred feet; the north segment is displaced to the east relative to the south segment, indicating that the south is the up-throw side. This fault contained much drag matter and has been stopped out between the offset limbs of the main vein (fig. 3 Plate VI). The whole country in the vicinity of the veins has suffered dynamo-metamorphism; the shales are contorted into small sharp folds and the included quartz veinlets are similarly distorted. The schistosity of the rocks is independent of the dip of the veins. The quartz of the veins is somewhat porous and stained from oxidation.

Under the microscope it is seen that the original quartz has been highly sheared and cemented by quartz of finer grain. Both kinds of quartz have pronounced wavy extinction. The secondary quartz
grains have highly irregular outlines. Original shale inclusions in the vein now appear as wavy ribbons of dense sericite; some sericite also occurs as a cementing material. These characters are also possessed by quartz of the smaller veinlets. The larger veins are accompanied by a gouge of sheared and altered shale.

Development operations below the 90 foot level exposed numerous stringers of quartz and calcite containing bornite, chalcocite and chalcopyrite. Thin sections of specimens from the dump show that these veins have a different history from that of the quartz veins already described. There is no shearing; the quartz is irregular, and in small stringers shows a tendency to comb arrangement on the walls with flamboyant quartz in the center of the veinlets. On polished surfaces the sulphides are seen to have smooth mutual boundaries. The chalcocite and bornite are graphically intergrown in some areas. The chalcocite is a mixture of pale blue and white chalcocite.

According to R. Gruss, the lessee in 1925, the rich gold ore was associated with copper minerals. The sheared quartz veins are evidently older than the latest granodiorite intrusives, which show no evidences of dynamic metamorphism. The copper-bearing veinlets
are free from the effects of shearing, and are clearly younger than the sheared quartz veins. No specimens of the rich gold ore were studied, and it is not known whether the values were introduced by the copper-bearing mineralisation or are of earlier date. The copper-bearing veinlets are said to have low gold content, while the sheared white quartz carries notable values. It is therefore probable that the gold in the rich ore was the original gold of the older veins.

A short distance up Ward Creek from the Gruss Mine is the Five Bears mine. The workings consist of a long tunnel driven in the spur between Ward Creek and Goodhue Creek. The tunnel is now caved and the workings are inaccessible. The mine has been shut down for many years. The chief values were in gold\(^1\), and the ore was treated in a stamp-mill which still stands. The country rock is Robinson shale and sandstone, and quartz stringers of the older type are abundantly exposed on the spur above the tunnel. The ore seems to have been of a type similar to that of the Gruss mine\(^1\).
Ward Creek Copper Area.

In the region between Ward Creek on the west and the granodiorite and overlapping basalt on the east there occurs a scattered copper mineralisation in the Kettle and Trail formations. There are numerous prospects of this type in the Kettle meta-andesite on the east bank of Ward Creek. In all of the adits visited the mineralisation is in the form of small stringer veins of quartz and calcite with sharp walls marked by thin talcose seams. Bornite, chalcopyrite and chalcocite are locally abundant in these veinlets, and specular hematite is a characteristic associate.

A thin section of quartz from ore of these veinlets shows no shearing. The quartz individuals are of anhedral shape, often elongated, and possess anomalous extinction. In the elongated forms the anomaly is of flamboyant type, and it seems probable that the anomalous extinction is due to the mode of crystallisation of the quartz. The curved foils of specularite are often conformable to the texture of the vein quartz. Sericite and chlorite are associates. These veinlets appear to be normal moderate-depth veinlets, unaffected by dynamo-metamorphism.

Later processes of jointing and minor faulting in the Kettle meta-andesite have produced shear
zones on the walls of some of these veinlets. Surface waters have altered some of these shear zones to clay; the sulphides are in part oxidised to carbonates, and the calcite is usually stained a deep brown. The prospects in the Trail formation immediately south of Genessee Valley are somewhat inaccessible and were not visited. At least one prospect is under active development. Some material from this property was received through the kindness of Mr. Frank Beardsley. The deposit is said to consist of disseminated sulphides and quartz stringers in porphyry and black slate. The material shows a quartz veinlet with massive chalcopyrite, between sharp walls in a dense black rock. In polished surfaces the chalcopyrite is seen to contain minor amounts of bornite and arsenopyrite. This veinlet is apparently of moderate-depth type.

On the outcrops of the Kettle meta-andesite there occur occasional veinlets of quartz and calcite with some specularite but no copper. Similar material is often found as float. These occurrences are probably of the same general type as those of the Ward Creek copper area. The copper-bearing veinlets at Gruss mine also fall under this classification.
Grizzly Vein Group.

On the surface in many places south of the Fortieth parallel, in the hornfels area, there occurs white quartz float sometimes in large boulders. These are of rather coarse white quartz sometimes vugs. Veins of this type are rarely found outcropping in this district, but some are to be seen in the underground workings of Walker mine. The Grizzly prospect is located on a vein of this kind.

Grizzly prospect.

This prospect was located by Smith and Sites some fifteen years ago. The short upper tunnel exposes a massive quartz vein up to 5 feet wide. The country rock is Taylor porphyrite; the walls of the vein are marked by a green alteration seam. Under the microscope this appears as a recrystallisation of the uralite-porphyrite to a felted mass of much coarser actinolite with interstitial pale green chlorite. The vein has a heavy fault on the north side which probably intersects it. In the vein occur bunches of chalcocite with subordinate bornite. The quartz has good crystal form against the sulphides, as if the sulphides were vug-fillings; good prisms of quartz penetrate the sulphide masses. In polished surfaces the chalcocite is seen to consist of the pale blue and white varieties,
intergrown in blades and irregular areas. The bornite has smooth boundaries to the chalcocite, or is graphically intergrown with it. The ore is in part oxidized to malachite. Near malachite veinlets the bornite is partly altered to chalcocite of a strong blue color, which between crossed nicols shows the presence of specks of covellite. This sky-blue chalcocite is probably a product of oxidation of the bornite (fig. 1, 2, & 3, Plate XIV).

A tunnel 600 ft. long has been driven into the hill 200 ft. below the upper tunnel, to find the vein in depth. This tunnel intersected and followed the fault referred to above, but did not find the vein, which may have been cut off by the fault. In the fault-gouge occur drag fragments of quartz and calcite with copper stain.

The Grizzly vein is said to contain a little gold and silver. It is of moderate-depth type, and may be persistent in dip and strike.
Contact Metamorphic Deposits.

Deposits of copper sulphides occur locally in the sediments adjacent to the intrusive plutonic rocks. In sediments which originally contained calcareous matter the mineralisation is of the usual type, the sulphides occurring in completely recrystallised rocks. In relatively resistant rocks the sulphides occur in connection with veinlets of quartz, and the rocks contain relatively unaltered nuclei. This type grades over into the vein-deposits elsewhere described.

Highland Boy mine.

This deposit was prospected about fifteen years ago and some copper ore was found, but no commercial ore deposits seem to have been located. The workings are now caved. The deposits occur in an isolated block of Robinson sediments, which is enclosed by the Nix porphyrite on the north, east and west and by the granodiorite on the south. The eastern half of these sediments was largely feldspathic in composition and the deposits occur in the western half, which contained calcareous matter.

Thin sections of ore from the dump show that the original rocks were of various kinds, such as impure limestone, calcareous shale, and arkose sediments.
These now show little of the original structure, except that original quartz and feldspar grains are relatively unaltered. These minerals are now sheared and corroded. The remainder of the rocks are almost entirely recrystallised and consist of heavy silicates in a groundwork of calcite and feldspar or in a dense mosaic of quartz and plagioclase. The heavy silicates are brown and green garnets, diopside, actinolite, and minerals of the epidote group. Other minerals are colorless and brown mica, titanite and apatite. Later alteration is unimportant, but gives rise to some sericite, chlorite, and fine epidote, derived chiefly from biotite and plagioclase. One dark green rock is seen to be a recrystallised arkose sediment. It consists of a quartz plagioclase mosaic, containing remnants of older feldspar and abundant deep-colored pleochroic secondary hornblende. A little deep-colored pleochroic pyroxene (hedenbergite) and much secondary magnetite are present. In one section a green pleochroic mica with strong birefringence was noted; it appears to grade into colorless mica.

Much of the material shows plentiful fine sulphide grains under the microscope, and occasional larger grains occur in hand-specimens. The sulphides are bornite and chalcocite. Large grains in polished surfaces show that the sulphides present smooth boundaries to each other, and are often graphically intergrown. The
grains show no clear evidence of having replaced other minerals; they conform to the irregular grain of the rock, and occasionally the heavy silicates possess good crystal form penetrating the sulphides. The sulphides are often enclosed by an envelope of clinozoisite (fig. 1, Plate XIII; fig. 4, Plate XIV).

Lena mine.

The Lena claim was located by the Sobero brothers some fifteen years ago, and passed into the control of an exploration company, which prospected the deposit. No production is recorded from this prospect.

The Lena workings are half a mile west of the Lower Camp. They consist of two tunnels driven into the hornfels adjacent to the granodiorite contact, one near the brow of the ridge and the other half way down the slope. The upper tunnel is in the zone of weathering and is now caved. The lower tunnel was open in 1924 and was examined in detail. In 1925 it also began to cave near the portal, and material for examination had to be taken from the dump.

The lower tunnel traverses the contact; a number of cross-cuts serve to expose the adjacent altered rock. The altered sediments are of three general types. The exposures in the lower tunnel are in part of a dense brown siliceous rock, resembling quart-
zite but locally containing fine chalcopyrite in streaks and specks. Under the microscope this is resolved as a very dense quartz mosaic in which are embedded numerous minute diopside prisms and magnetite grains. It is traversed by small streaks of quartz containing very fine grains of chalcopyrite, bornite, pyrite, and pyrrhotite in intimate association with clinozoisite and a small amount of sericite. These sulphides are also disseminated through the rock in finer forms.

There occur small amounts of crystalline hornblende-biotite schist. In thin section this is resolved into a dense mosaic of quartz and plagioclase containing abundant crystals and aggregates of hornblende, biotite, and magnetite. These minerals possess schistose orientation. Small amounts occur of a non-schistose dense rock composed almost entirely of hornblende.

The originally calcareous zone is represented by heavy silicate rocks containing a small amount of recrystallised calcite. One drift face is in massive actinolite asbestos; another is in a spotted rock composed of garnet crystals up to 2 inches in diameter embedded in dense fibrous wollastonite. There are also exposures of coarse vuggy epidote with associated white mica. Much of this altered calcareous rock is of obscure composition, but epidote, brownish garnet,
and recrystallised calcite are generally visible. On the dump of the upper tunnel there is abundant copper-bearing material, consisting of massive garnet, calcite and wollastonite rocks with plentiful grains of bornite and chalcopyrite.

In thin section these altered calcareous rocks appear as irregular aggregates of garnet, epidote, actinolite, and diopside in a groundwork of calcite, quartz, plagioclase, feldspar, and wollastonite. Other minerals are apatite, titanite, magnetite, chlorite, clinozoisite, and sulphides. In polished surfaces the sulphide grains are seen to consist of bornite, chalcopyrite, and sky-blue chalcocite. The chalcopyrite is partly intergrown as blades in the bornite, and partly in smooth rounded forms. There is every transition from grains of bornite with chalcopyrite blades, to bornite with included rounded forms of chalcopyrite, to grains which are clear bornite on one half and clear chalcopyrite on the other half, and finally to chalcopyrite grains with included rounded forms of bornite. The sky blue chalcocite is nearly always peripheral, or occurs penetrating bornite along cracks or along chalcopyrite blades. The outlines of its embayments in the bornite are often irregular (figs. 2, 3, 4 Plate XIII).
In thin section the relation of the sulphide grains to the metamorphic rock is clearly brought out. The grains are often irregular, conforming to the irregular texture of the rock. In other cases the other minerals present good crystal faces towards the sulphides, or the smooth outlines of anhedral crystals embay the sulphides. In still other cases the rock seems to have been sheared, and the sulphides occupy the fissures traversing the other minerals. There is no definite evidence of corrosion or replacement of the other minerals by the sulphides. Not infrequently the sulphide grains are partially enclosed by an envelope of anhedral clinozoisite.

Near the contact a variety of differentiation types occur in the granodiorite. One is a coarse-grained pegmatitic rock characterised by rosy feldspar and plentiful quartz; there is usually some biotite and hornblende, in proportions up to one-half of the rock. Sometimes the grain is much finer and the rosy tint is absent, approaching the aplitic type. Sometimes the quartz is predominant, sometimes the feldspar. The rosy feldspar is seen under the microscope to be microcline, or intergrown microcline and plagioclase, occasionally with intergrown and included quartz. Aplitic intergrowths occur in small areas. The hornblende is of the normal variety but
is of ragged shape, sometimes enclosing much quartz. Titanite, apatite, magnetite, and ragged tourmaline are accessories. The quartz has very irregular outlines, shows anomalous extinction, and contains abundant minute fluid inclusions with gas bubbles. Biotite is usually scanty. These rocks have suffered some hydrothermal alteration, with production of chlorite and fine sericite and epidote. They have been sheared towards the close of the epoch of mineralisation and are traversed by small veinlets of minerals of the epidote group.

The altered sediments are traversed by numerous pegmatitic veins and veinlets up to two feet in width. These veinlets grade into varieties composed chiefly of quartz, with black tourmaline (schorl) and a little molybdenite as notable accessories. The schorl sometimes appears to be graphically intergrown with quartz. In much of the material these pegmatitic stringers seem to have penetrated the sedimentary rocks at random, enclosing and partially absorbing small blocks of the country rock, with recrystallisation to epidote, garnet, and anhedral calcite. There is some associated development of sulphides, especially cubes of pyrite.
of quartz whose outlines are obscured by the recrystallisation of the whole rock. In some cases coarse grains of bornite and chalcopyrite characterise these quartz streaks. In some specimens the sulphide grains seem to be localised near the quartz, diminishing in number and size in the recrystallised rock as the distance from the quartz streaks increases. The grain-size of the garnet and epidote in these specimens appears also to reach a maximum adjacent to quartz or pegmatite areas.

The pegmatitic material not infrequently shows the presence of chalcopyrite grains of notable size and amount⁴. These chalcopyrite grains however do not present an appearance of having consolidated at the same time as the silicates. They lie almost invariably between feldspar grains, or traverse feldspar grains in cracks associated with secondary minerals.

Some hand-specimens of hornblende-biotite schist from the Lena dump show small lenticular aplitic injects which are associated with lenticular veinlets chiefly of quartz with some sulphides. These were examined with care in thin section and polished surface, under the impression that they might be miniature injected veins. The country rock is composed of hornblende and biotite aggregates in a dense mosaic.
of anhedral quartz and plagioclase feldspar with a little pyrite, pyrrhotite and magnetite. The veinlets are of much coarser quartz, with irregular boundaries and anomalous extinction, containing minute solid inclusions (apatite, biotite, etc.) and fluid inclusions with mobile gas bubbles. Embedded in the veinlet quartz are coarse grains of hornblende and smaller amounts of biotite and diopside together with pyrrhotite and pyrite of interstitial character. There are inclusions of the much denser country-rock in the form of little drawn-out "horses"; the dense grain of these grades into that of the veinlets, which in some cases are split by larger inclusions of the schist. The quartz veinlets appear to be genetically related to the aplitic lenses in the same hand-specimen. Molybdenite occurs locally in these aplitic injects. The vein quartz is crystallised into the country rock in an abrupt but not linear transition; it does not appear to have been dynamo-metamorphosed. The veins are apparently of the same age of crystallisation as the schist. There has been a little later hydrothermal alteration. The textural characteristics of these veinlets are somewhat analogous to those of the Walker mine veins, and their relation to aplitic injects is of interest in this connection.

It would seem that some part of the alter-
ation of the sediments at the Lena mine is due to the action of pegmatitic injects; the exposures are however insufficient to permit of definite conclusions as to the mode of the contact metamorphic action. The pegmatitic rocks themselves were observed in some detail; they afford some indication of the differentiation habit of the adjacent plutonic rock.

McGill's Tunnel Area.

In the area between the Lena mine and McGill's tunnel, and along the contacts of the McGill porphyrite with the hornfels and the Nix porphyrite, there are occurrence of a mineralisation which is closely associated with contact metamorphism but tends toward the vein-forming type.

On the hill above the Lena workings there occur numerous irregular quartz-rich veinlets in a knotted hornfels (fig. 2, Plate VII). Some of these are characterised by feldspar content, with or without metallic minerals. In one exposure bunches of massive hematite occur in a coarse quartz matrix. In thin section the presence of plagioclase feldspar and a little microcline is seen; augite and titanite are present. The quartz has been sheared and possesses both the common anomalous extinction and that of the "wavy" type due to strain. In the polished surface the hematite is seen to contain minor amounts of magnetite in
included grains of smooth anhedral outline.

On the contact of the Nix and McGill porphyrites there is locally a notable development of white quartz in irregular veinlets, frequently associated with coarse and fine aggregates and crystals of minerals of the epidote group, chiefly common epidote. Some copper mineralisation is also present, and gives rise to green stains in the rocks exposed by the numerous prospect trenches along and near this contact.

On the hill above the McGill tunnel this form of mineralisation has been exposed by numerous trenches on and near the contact of the McGill porphyrite with the hornfels. In thin section the ore is seen to consist of McGill porphyrite partly recrystallised to a dense biotite-quartz-sericite rock containing little-altered feldspar phenocrysts. This rock is traversed by secondary quartz of coarser grain in irregular veinlets and patches, associated with epidote, chlorite and grains of bornite. The bornite grains are often partially enveloped by clinozoisite. In places the rock is amygdaloidal in appearance. The amygdules consist of aggregates of secondary amphibole, quartz, and an undetermined colorless unstriated mineral resembling feldspar. There is plentiful associated epidote, sericite, and chlorite. Not infrequently grains of bornite occur in the centers of these amygdules. The
dense groundmass is in part recrystallised, though
the feldspar laths are still recognisable; abundant
fine secondary quartz, biotite, magnetite, and actinolite
are scattered through the mass, and later chlorite,
epidote, sericite and magnetite are plentiful in very
fine forms. Fresh apatite and a little bluish tourma-
line are present.

It is not clear whether this mineralisation
is to be ascribed to the expiring phases of the adjacent
contact metamorphism or to solutions originating at
greater depth. It is local in extent and the impreg-
nations are of low grade, due perhaps to the resistance
to replacement of the porphyrite and hornfels.
WALKER MINE.

The crest of Rocky Point is composed of silicified rocks which contain a system of quartz veins dipping about $60^\circ$ E and striking about N $25^\circ$ W. The greater part of the outcrop is composed of silicified rocks without distinct quartz veins. Strong quartz veins outcrop at the south and north ends of the belt, near the edge of the overlying basalt, and numerous small stringer veins outcrop on the northern slope of Rocky Point. The southernmost massive quartz outcrop was prospected by a shaft at what is now the Upper Camp, and commercial bodies of copper ore were found. Subsequent mining operations were carried on from an adit driven from what is now the Lower Camp, about 700 ft. below the Upper Camp outcrop. The original shaft (fig. 2, Plate VI) was sunk into a strong and consistent quartz vein carrying commercial amounts of chalcopyrite; this vein is cut off on the north by a fault, and on the south by a granitic dike. The ore body so defined will be described as the "central orebody"; the orebodies north and south of this will be described under the headings "north end" and "south end" respectively.
Igneous Rocks.

Adit Granodiorite.

Occurrence.

This plutonic rock outcrops on the surface at the Lower Camp, and probably has a considerable extent under the overlying basalt sheet. It is limited by the altered sediments on the north. On the surface and for a depth of several hundred feet the effect of weathering is pronounced; it is therefore difficult to ascertain its character in detail in the surface exposures. Boulders of float from this rock have the general character of the granodiorite elsewhere described; they are of medium grain with abundant quartz and less plentiful hornblende and biotite. There are occasional dark secretions of denser grain. Pegmatitic float is plentiful on the surface.

The exposures in the first 1500 feet of the adit also show the effect of weathering. Beyond this the relatively fresh rock has a somewhat lighter color and finer grain than that of the surface exposures; dark secretions are moreover absent. It is not known whether this rock is a separate intrusive or a marginal facies of the rock exposed on the surface. No abrupt transition or contact could be found. These rocks in the adit are traversed by numerous joints and small
faults of no regular attitude. Aplitic dikes of small width are common, and are frequently accompanied by soft alteration seams which have been sheared into gouge seams by later movement.

The contact of the adit granodiorite with the altered sediments and their contained quartz veins is a true intrusion contact, marked by little alteration. The contact is irregular and the veins terminate abruptly against the granodiorite. In places the granodiorite has undergone more or less pronounced alteration, resulting in some cases in the production of a soft greenish rock of obscure texture. In such localities the adjacent hornfels is also somewhat altered. Occasionally small pegmatitic dikes traverse the contact into the hornfels. No sulphides were seen in any of the aplitic dikes.

Character.

Under the microscope the adit granodiorite is seen to consist chiefly of quartz and feldspar, with subordinate biotite and hornblende. The proportions, which are sensibly the same in all sections of the fresh rock, are about 40% quartz, 40% plagioclase feldspar, 10% biotite, and 5% hornblende. Some microcline is present. The feldspar phenocrysts are often strongly zoned, and vary in composition from labradorite in the centers to oligoclase on the margins. Pericline twin-
ning is often combined with the common albite form. The quartz is interstitial, shows anomalous extinction, and contains abundant minute fluid and solid inclusions. The biotite and hornblende are of the common varieties.

The texture of this rock differs from that of the normal plutonic type. The plagioclase is in pheno-
crysts embedded in interstitial anhedral quartz and occasional microcline grains which show little or no twinning. The plagioclase grains are often bordered by fringes of fine aplite intergrowths of quartz and unstriated feldspar, possibly microcline. The biotite, though occasionally forming large independent crystals, occurs commonly in clumps of small crystals matted together, and containing apatite, magnetite, titanite and zircon grains. The hornblende is in larger crystals of ragged outline. These minerals are intimately associated with fine quartz, surrounding the feldspar pheno-
crysts and coarser quartz, and appear to constitute an interstitial complex of later crystallisation than the larger crystals. In some cases small biotite laths cut across plagioclase grains, but in general the bio-
tite and hornblende are moulded on the plagioclase.

This interstitial complex has a tendency to form strings traversing the section between plagioclase grains. The accessory minerals appear to be concentrated in and near the biotite aggregates, but occur also throughout
the rock.

This rock has undergone some hydrothermal alteration. The biotite is in part altered to chlorite in parallel position, the feldspar is clouded by fine forms of sericite and epidote, and occasional larger grains of epidote occur. In some places adjacent to the contact the alteration is strong. In some cases there is formed a soft greenish rock composed almost entirely of quartz, sericite, chlorite, epidote, actinolite and calcite; the original quartz is unchanged, but only traces of the original feldspar, biotite, and hornblende remain.

The pegmatitic and aplitic dikes vary considerably in character, and are considerably altered. They consist of quartz with varying amounts of plagioclase feldspar, microcline, and a little biotite and colorless mica. Alteration products are chlorite, sericite, epidote, and calcite. Aplitic intergrowths are well developed.

Relation to the Vein System.

The adit granodiorite truncates the Walker veins (Plate V). A series of thin sections from points at intervals along the adit fail to show any variation in essential character of the rock. It is not unlikely that the rock in the adit is a marginal facies of the more normal rock near the Lower Camp. It seems
clear that this rock has no genetic connection with the Walker ore-bodies.

Granitic Dike.

Occurrence.

This rock occurs as a dike somewhat south of the main orebody. It is split into two members, the relations of which are obscured by faulting (Plate I). The outlines are irregular, but the dike appears to cut the vein system at a large angle. The contact is an intrusion contact, modified by a small amount of later faulting on the margins of the dike. The veins are offset fifteen feet or so by the dike, but the direction of relative movement is not known. The intrusion has no genetic connection with the Walker mineralisation.

In several of the drifts driven in this rock the results of routine grab sampling by the Walker Mining Co. show the presence of copper in amounts up to 0.75%. The consistency of some of the assays, and the amounts of copper reported, indicate that these results are not altogether due to contamination of samples, and that the rock has locally a notable content of copper. This fact, and the peculiarities of the rock itself, led to a detailed study of this occurrence.
Character.

In hand specimen the rock is medium-grained, with abundant quartz and less abundant feldspar, and some dark minerals in much finer forms. In thin section the rock is seen to be composed of about 50% quartz, 30% plagioclase, 10% microcline, 5% biotite and some colorless mica. The composition varies somewhat in different sections. No hornblende was noted. Accessory minerals include tourmaline, apatite, magnetite, titanite, zircon, and pyrite.

The quartz possesses anomalous extinction and numerous minute fluid inclusions, some with gas bubbles. The outlines are often complex. The plagioclase phenocrysts are often strongly zoned, and vary in composition from andesine-labradorite in the centers to oligoclase externally; albite and pericline twinning are well developed. The microcline seldom shows twinning; it is distinguishable by the cleavage, low relief, interstitial character, and alteration. The biotite is of the common variety, and contains numerous pleochroic haloes surrounding inclusions of apatite and zircon. The colorless mica has small optic angle, and is probably damourite.

The texture of this rock is similar to that of the adit granodiorite, but the interstitial complex
of quartz, microcline, biotite, and colorless mica is more highly developed (Plate X). Hornblende is absent, and tourmaline and colorless mica are characteristic. The biotite in some instances cuts across plagioclase feldspar, and is sometimes developed in small laths in the zones of zoned crystals of plagioclase (fig. 1 and 2, Plate XI). The tourmaline is pleochroic in blue and violet tints (Schorl) and occurs in irregular forms replacing microcline (fig. 3, Plate XI), as rough short prisms, and as well-formed needles and prisms in feldspar. There is strong alteration of the hydrothermal type, apparently in two intergrading stages: (1) the development of coarse irregular damourite replacing plagioclase and especially microcline; (2) the development of finer sericite, epidote, and calcite in the feldspars, and the alteration of biotite to chlorite. Coarser epidote and calcite are also formed in this second type. It seems probable that the development of coarse irregular colorless mica is in some way related to the presence of tourmaline and is analogous to the process of greisenisation. These characters give the rock a complex appearance in thin section.

None of the sections studied show the presence of copper minerals, though pyrite seems to be a
common accessory mineral in small amounts.

**Acid segregates.**

The granitic dike gives rise to a number of acid segregates in the form of small pegmatitic veins. These are often associated with a coarse pegmatitic phase of the main rock, into which some of them grade in part of their length, while in other parts they have sharp walls. Several thin sections of this associated pegmatitic phase reveal it as an aggregate of coarse quartz and feldspar. The quartz possesses pronounced anomalous extinction, complex outlines, and numerous fluid inclusions. The feldspar is complex of microcline and plagioclase with intricate pericline and albite twinning; intergrown fine quartz and coarse secondary colorless mica are abundant (fig. 4, Plate XI). Hydrothermal alteration is marked. In another section the rock is similar to the main rock but with much colorless mica and some tourmaline in needles.

At the north contact of the granitic dike on the adit level there occurs a pegmatite veinlet up to 3" in width. This arises in the dike and traverses the contact into the hornfels. It carries visible grains of chalcopyrite. The rock is coarse-grained and is composed of quartz, microcline, plagioclase,
colorless mica and chlorite. The chalcopyrite occurs associated with chlorite, colorless mica (damourite) and calcite (fig. 4, Plate XII).

On the fifth level near 575 Raise there occurs in the dike a coarse quartz veinlet carrying molybdenite. The quartz contains some feldspar in small crystals, apparently both albite and microcline. Other irregular veinlets carry tourmaline in quantity. All these pegmatitic occurrences are characterised by heavy alteration. The original biotite is almost entirely altered to chlorite; the feldspars are replaced in part by damourite, and there is much development of fine sericite and epidote.

Dense Quartz Diorite Dike.

Somewhat north of the granitic dike the main ore body is cut by an almost vertical occurrence, 2-6 ft. thick, of a dense dark rock striking N70°-80°W. This is readily distinguished from the hornfels by its greater density of texture. It is jointed into small plane-faced blocks, and the joint planes have suffered some weathering action. This rock is locally known as a quartz diorite dike. It occurs on all levels of the main orebody, but was not noted on the surface. It is associated with small faults and the vein is offset a few feet by it.
This occurrence was studied on the adit level only, since caving operations had rendered the upper levels inaccessible. A series of thin sections of specimens from the adit level showed only a dense recrystallised siliceous rock, with distinct schistose structure and wavy extinction in the quartz grains. These sections indicate the existence of a localised zone of shear under great pressure. The adjacent hornfels is relatively free from these characters; it is of coarser grain and is not similarly jointed. Igneous material, however, is said to occur in this jointed rock.

**Central Orebody.**

The central, or main orebody consists of a body of massive quartz carrying sulphides, occurring in a dark crystalline hornfels of fairly dense grain, and containing lenticular horses of the country-rock. The vein strikes $N25^\circ W$ and dips $50^\circ-70^\circ$ east. The thickness varies from 10 ft. on the adit level, and on the southern end, to a maximum of 75 feet on the second level near the north end. The vein diminishes in width from north to south, and from the upper levels to the adit level. The quartz of the vein is frozen on the walls; the transition zone is narrow, usually no more than an eighth of an inch. The contact is rarely a smooth plane, and small irregularities are
common. The country-rock immediately adjacent to the contact is often characterised by the development of coarser garnets and biotite flakes than are found in the rock at a distance from the vein.

The horses in the quartz are of a rock similar to that of the walls, and also frequently show a coarser grain near the quartz vein. They vary in thickness from a few inches to a few feet, and their length and height is many times their thickness. They form tabular bodies lying parallel to the vein walls. Between the adit level and the fifth level the horses are few in number, and constitute only a small part of the commercial orebody; they increase in number and size above the fifth level, and towards the surface above the third level they constitute a large part of the vein as mapped in Plate II. Above the second level the vein consists of a belt of quartz veins from a fraction of an inch to ten feet in width, lying parallel to each other and separated by tabular horses of hornfels. Due to the lean character of the horses the average tenor of the vein becomes too low for stoping, and stoping operations above the second level were confined to the larger members of the vein-system.

In shape the central orebody vein is somewhat irregular. (See plates II and III). The general decrease in cross-section from the surface downwards is
interrupted by numerous small rolls in the hanging and foot walls. In the central part of the vein two smaller veins join the main body. One is known as the "hanging-wall vein"; it strikes nearly parallel to the main vein but has a steeper dip, and lies in the hanging wall. The line of junction runs from the second level to a point between the fourth and fifth levels, pitching south at a small angle. This vein is in places 15 ft. wide and was stoped in part of its length. It pinches out upward and southward. The other stringer joins the vein between the fourth and fifth levels on the footwall. It is of small size and pinches out downward. A strong swell in the main vein occurs between the junctions of these two small veins (Plate III).

In the country-rock adjacent to the vein occur parallel stringers of quartz of similar type. These are all of small size and decrease rapidly in size and number away from the orebody, but isolated examples are found at a distance of fifty feet or more from the orebody. The width may be as much as eighteen inches, but the commonest width is only a few inches. Where the main vein near the walls contains numerous horses (as on the upper levels) the location of the vein wall becomes a matter of definition. On the second level hanging-wall side, for instance, the mineralisation may be said to fade out into the walls as the
stringers diminish in size and frequency. In general, however, the limits of the main vein are clearly defined. These parallel stringers are of the same type as the main vein, have fairly sharp walls, and are frozen to the hornfels.

The valuable mineral in the ore is chalcopyrite, which is concentrated from the ore and shipped to the smelter; the concentrates contain a little gold and silver. The greater part of the copper content is enclosed in the quartz, but the associated hornfels, due to the presence of very small quartz stringers and to the mineralisation accompanying the formation of the vein, also contains a little chalcopyrite. Wide sections of the hornfels exposed in crosscuts average from 0.09% - 0.35% of copper; the quartz carries up to 25% of copper. The grade of the orebody is therefore determined in part by the amount of included hornfels in the vein. The amount of included matter exercises also an important influence on the grade of the quartz veins proper; where these occur as small stringers they are usually lean in copper, while in sections of the orebody which are ten to thirty feet in width, with almost no inclusions, the sulphides are often almost massive.

Country-rock.

The country-rock of the central ore-body,
although varying somewhat in mineral composition and
grain from place to place, is fairly uniform in
character. In hand specimen it is a fairly dense rock,
gray to almost black in color, without visible schis-
tose structure, and hard and tough under the hammer;
it breaks with a rough conchoidal fracture. Specks
of chalcopyrite, crystals of dark reddish garnet,
and flakes of biotite are often visible. In places,
adjacent to quartz, it is of coarser grain, and coarse
biotite flakes and garnets up to one-half inch in
diameter occur. This rock is locally known as schist.
As it is a typically nonechistose recrystallised rock,
owing its character to alteration by ore-forming
agencies of high-temperature type, or by igneous
agencies, the name "hornfels" is perhaps more applic-
able.

Under the microscope this rock is seen to
consist of a mosaic of anhedral quartz and calcic
plagioclase in which are embedded single grains and
aggregates of biotite, garnet, enstatite, and magne-
tite. Tourmaline occurs in scanty short prisms; a
colorless mica, with small optic axial angle (damou-
rite) occurs in well-formed laths associated with the
biotite; and small prisms of apatite are sparingly
distributed in the mass. The biotite is of the common
variety. The garnet is isotropic and brownish-red in color. The enstatite is in medium-sized ragged individuals with numerous inclusions. The tourmaline is pleochroic violet to deep blue (schorl). The magnetite is in rough grains or in anhedral crystals. The quartz contains very numerous solid inclusions, most of which appear to be biotite in small laths with rounded terminations, or in rounded plates. Some of these inclusions may be tourmaline, but their small size renders determination difficult. The quartz contains a few minute fluid inclusions.

The hornfels is traversed by a great number of microscopic veinlets of relatively coarse anhedral quartz containing abundant minute solid and fluid inclusions. These little veinlets are frozen on the walls; the contacts are not linear, since the smaller grains of the hornfels interlock to some extent with the larger grains of the veinlets. The contact is often obscured by strings of magnetite grains. Magnetite also occurs centrally in some veinlets, associated with a green pleochroic biotite. Specks of chalcopyrite, pyrrhotite and pyrite frequently occur in the hornfels. These small sulphide grains appear to be of the same age as the crystallisation of the rock.

The contact of the hornfels with the larger
quartz bodies was not studied under the microscope, but is probably of the same grain-to-grain interlocking type. The evidence seems to show that the recrystallisation of the country-rock was contemporary with the formation of the veins.

The hornfels is little altered, except that some fine sericite and epidote occasionally occur on the edges of feldspar grains, and that the biotite is sometimes partly altered to chlorite, or shows a dull brown color. There is in general no evidence of dynamic metamorphism; the quartz shows no wavy extinction, except in hornfels near the dense quartz diorite dike, as elsewhere noted. In some places the rock has a schistose appearance due to oriented elongation of the biotite-garnet aggregates. In such cases the schistosity is approximately parallel to the vein walls.

Vein-matter.

Almost the entire vein-filling consists of a medium to fine-grained massive quartz, containing varying amounts of sulphides, magnetite, and small amounts of silicate minerals. Under the microscope typical specimens appear as an aggregate of anhedral quartz grains, which contain abundant minute fluid inclusions with gas bubbles and a few minute solid inclusions apparently of biotite, tourmaline and apatite. The quartz shows no distinct wavy extinction but the larger grains
show extinction anomalies, as if composed of smaller individuals which are oriented in slightly different directions.

Specimens of vein quartz lean in copper contain aggregates of biotite, magnetite, pyrrhotite, chalcopyrite and occasionally pyrite, with small amounts of tourmaline, damourite, and sometimes garnet. These minerals are not distributed through the quartz, but occur as aggregates of irregular shape. The aggregates show in general an interstitial appearance, and are nearly always embayed by smooth-outlined quartz grains, or (if small) appear to lie between quartz grains. In some cases, however, these minerals appear to embay or penetrate quartz grains. The composition of these aggregates varies; some are of chalcopyrite with scanty associates; in others the silicates predominate. Magnetite is usually present in subordinate amount.

Although biotite appears to be the typical original associate of the sulphides, the vein-matter has suffered hydrothermal action, and chlorite, epidote, and infrequently actinolite, calcite, and sericite are the chief present associates of the sulphides. It is not clear whether these minerals are always alteration products of earlier minerals, or whether they were in part deposited in their present form. Remnants of biotite partly altered to chlorite in parallel position
are common. Chlorite however occurs most commonly in sheaf-like radiating aggregates, and in some cases penetrates the adjacent quartz grains. The calcite, epidote, actinolite, and sericite also penetrate the quartz in many cases.

The foregoing remarks apply to massive quartz carrying relatively small amounts of sulphides and silicates. The sulphide content of the main vein-filling varies from place to place, without sharp discontinuities; some of the higher grade ore is medium-grained with sulphide-silicate aggregates occupying the greater part of the volume, and some is of medium grain and tenor with sulphide bunches up to fist size. In these high-grade ores, and massive sulphide specimens, the characters differ from those of the leaner ores. They occur in the wider parts of the vein, which are notably free from country rock inclusions.

The rarer constituents of the ore, such as sphalerite and galena, attain a larger size in the massive ore, and are then evident under the microscope; they are probably present also in finer forms in the more finely disseminated ore. Moreover, there appears to have been some additional segregation of minerals in the high-grade spots, which has concentrated the rarer constituents into masses relatively free from the commoner ore minerals. The rarer minerals contribute
little to the copper output, but the small amounts of them present in the ore may account for part of the gold and silver content.

The character of the massive ores is described in the section on "Mineragraphy". It may be here noted that as the amount of sulphides increases the relation of the quartz to the sulphides changes. In specimens which are half sulphides (chiefly chalcopyrite and pyrrhotite) the quartz tends to assume smooth hook-shapes towards the ore-minerals; where the sulphides predominate the quartz grains become subhedral, and they assume somewhat imperfect crystal form when embedded in sulphides. In some hand-specimens of sulphide bunches the enclosing quartz has crystallised as prisms penetrating the ore-minerals. One such specimen, after the sulphides had been removed by solution in aqua regia, presented the appearance of a crystal-lined vug.

In the massive specimens the association of biotite, chlorite, epidote, calcite, and sericite with the sulphides persists. In grains enclosed by quartz, and apparently of interstitial character, the occurrence of these minerals is so distinct from that of the enclosing quartz that they appear to constitute a second generation of gangue, contemporary with the ore-minerals.

Besides the massive vein-filling there occur
in the main vein several types of veins of later age, which appear to be characteristic associates of the main vein-filling, and for which no external origin could be found. They are of little economic importance, but may throw some light on the problem of the genesis of the main veins. There are few exposures of these veins in development openings, and they are confined almost entirely to the orebody itself. The operations of shrinkage stoping in this orebody afforded progressive cross-sectional exposures in the stope backs, and the following notes are from observations made in the stopes by the author during a year's connection with the Walker Mining Company.

There occur in the main vein-filling irregular bodies a few feet wide of milk-white massive quartz of much coarser grain than the common ore. This quartz grades into the common type in a few inches; where these white quartz bodies are in contact with country-rock they often penetrate the vein-walls a few feet into the hornfels; the contact with hornfels is marked by thin damourite seams and some garnet. These bodies carry some chalcopyrite and damourite in infrequent spots up to two inches in diameter, which have the character of vug-fillings penetrated by crystals of the enclosing quartz.

These bodies are in some cases connected with
veinlets of the same type, and many veinlets of this type occur without evident connection with milk-white quartz bodies. These veinlets are sometimes irregular in outline, but more often lie between plane walls, and have the appearance of fissure veins. They traverse vein and horses in all attitudes, and sometimes penetrate a few feet into the vein walls. The maximum width noted is one foot.

These cross-veins sometimes contain a large proportion of sulphides. As the amount of sulphides increases the presence of biotite becomes notable, and the quartz adjacent to the ore-minerals frequently assumes good crystal form. Well-terminated quartz prisms up to three inches long sometimes occur in these cross-veins. One such vein was observed in the back of the stope near the second level. It lay between plane walls cross-cutting a series of alternating quartz veinlets and small horses. The upper wall, as shown by the discontinuity of the structure, had been offset one foot northward relatively to the lower wall. These veins therefore appear to have consolidated later than the main vein.

There are occasional small occurrences in the higher grade portions of the main vein which do not possess the character of veins but which may be genetically
analogous to the cross-veins. These consist of coarse quartz prisms embedded in sulphides and associated with damourite, biotite, and spheroidal forms of dense pyrite.

In many parts of the main vein there are occurrences of barite, both as veinlets in all attitudes and as disseminated occurrences in the vein-matter, especially near the horses or vein walls. One of the veinlets noted was composed of massive barite in interlocking anhedral crystals up to one inch in diameter. The walls of this veinlet were plane, and the barite crystals were frozen on the vein-quartz walls. This veinlet carried fine disseminated magnetite and some chalcopyrite. Under the microscope this ore appears as a mosaic of anhedral barite grains, containing aggregates and scattered grains of magnetite, chalcopyrite, and a little sphalerite. These minerals present smooth rounded outlines to the barite, except that the magnetite is sometimes euhedral. Associated with the sulphide-magnetite aggregates are chlorite and actinolite. The chlorite is brownish-green and between crossed nicols shows occasional flecks of high polarisation tints; it is probably a partly-altered biotite. The actinolite is apparently secondary. Some magnetite dust is present, associated with chlorite and actinolite; it is probably a by-product of the formation of these minerals.
The disseminated barite in parts of the main vein is usually in coarse anhedral forms up to one inch in diameter. It frequently contains chalcopyrite specks. Some specimens were obtained which show barite associated with pyrrhotite-chalcopyrite-quartz ore. Examination of a polished surface showed that the barite was not an original constituent of this high-temperature ore; the barite areas embay the quartz-sulphide complex on irregular lines suggesting that the barite is of later age.

In one case was noted a small barite veinlet cutting the country rock on the hanging wall of the main vein. This was associated with a fairly soft altered form of the hornfels, in which occurred cavities partly lined with small well-formed bipyramids. In a polished surface the veinlet referred to is seen to carry plentiful chalcopyrite and magnetite occurring as bands on the veinlet walls. In thin section the adjacent country-rock is seen to resemble the normal hornfels except that tourmaline and damourite are plentiful, and that hydrothermal alteration is well developed. The biotite is almost entirely altered to chlorite. Secondary epidote and clinozoisite are present in notable amount, and small areas of dense sericite occur. The rock is traversed by irregular veinlets and patches of much coarser quartz, with anomalous extinction and abun-
dant minute fluid inclusions; some pyrite cubes are present. Much of the coarser sulphides, magnetite, and fine sericite in the rock appears to be associated with these coarser quartz areas. Barite is present in some of this rock and presents smooth anhedral boundaries to the quartz grains.

Outcrop and weathering.

The central orebody reaches the surface in only part of its length. It is terminated by faulting a few hundred feet north of the upper camp, and is overlain by the basalt flows southward from a point a hundred feet south of the Upper Camp. The outcrop thus exposed is obscured by a mantle of detritus. As has been remarked, the vein in this section consists of a series of parallel stringers separated by horses of country rock. The strong footwall member, of massive quartz fifteen feet wide, is exposed near the collar of the old shaft. This is of brown-stained quartz containing cavities filled with porous limonite.

The first fifty feet of the vein in depth is much oxidized; massive sulphides are reduced to porous limonite masses still containing the roughly euhedral quartz grains which were embedded in the sulphides. The effects of oxidation diminish in depth. Under the Upper Camp, on the second level, some secondary enrichment has occurred; sulphide grains are found partly altered to
sooty chalcocite. In this zone blue stains of chalcanthite occur in the fracture planes of the ore, but copper carbonates are present only in very small amount. This zone pitches southward under the lava-cap and intersects the third level at the south end of the central orebody.

Below this blue-stained zone the effect of weathering is imperceptible, except near faults and channels of surface water circulation. Near such channels, down to the adit level, sooty chalcocite and spangles of native copper are found in small amounts. The opening of the mine has resulted in much recent oxidation. Broken ore left for two years on stope sills, and subject to action by percolating waters, was observed to possess a brown-stained upper layer and a black lower layer.

North End of Mine.

North of the faults which terminate the central ore-body, mining operations have exposed a system of quartz veins in hornfels which lack the simplicity and massive character of the central vein. Not only are horses and parallel stringers numerous, but the walls of the quartz veins proper are often indefinite, and much of the vein matter in this mineralised belt is difficult to classify, in hand-specimens, as either vein-quartz or country rock. The north end orebody possesses general
physical features much like those of the central ore-body; in Plate IV its shape and attitude are represented in a generalised manner.

**Country-rock.**

The country-rock a few feet distant from quartz veins in the north orebody is similar to that enclosing the central orebody. In places, however, especially on the third level, there is an increase in the amount of damourite and tourmaline; hydrothermal alteration is more marked, as shown by the alteration of biotite to chlorite with magnetite dust, and by local development of fine sericite and some epidote. Some cyanite was noted in sections of the north end country-rock.

**Vein matter.**

Some of the quartz ore in the north ore-body is similar in character to that of the central ore-body of moderate copper content. Much of it however is of light to dark gray color, sometimes with cloudy gray patches of irregular shape, or with darker gray bands. Under the microscope the darker varieties appear partly as a dense quartz mosaic carrying aggregates of chlorite and garnet with some sulphides and magnetite. These aggregates are usually elongated and in schistose arrangement. This dense complex is traversed and enclosed by irregular patches and veinlets of much coarser quartz, relatively free from silicates and possessing no
Schistose structure. The dense quartz often shows traces of wavy extinction, and contains fine solid inclusions, with relatively few fluid inclusions; the coarser quartz appears to lack wavy extinction, but shows extinction anomalies similar to those of the quartz of the central ore-body. It contains numerous fluid inclusions, frequently in strings. The dense quartz complex often contains plentiful damourite and tourmaline; hydrothermal alteration is marked, and epidote, fine sericite patches, and sometimes calcite are present. Microscopic fissures are occasionally seen, filled with chlorite and sometimes chalcopyrite and pyrite.

In some localities veins of massive quartz of the central ore-body type fade into the country-rock by a progressive increase in the content of silicates, especially garnet. The intermediate phase, as seen under the microscope, consists of approximately equal areas of coarse quartz and dense quartz of the types described above. Tourmaline, damourite, chlorite, sericite and epidote are characteristic. The abundance of garnet and enstatite give the rock as distinctive appearance, but it is of the same genetic type as the "dark quartz" already described. Red or pink spots are common in the massive quartz. These are aggregates of brownish-red garnet with associated chlorite.

Though the copper content of much of the ore-
body is low, due to the amount of included country rock, the occurrence of many bodies of massive quartz, irregularly distributed through the mineralised belt, makes possible the mining of large tonnages of ore. In some localities the gray quartz carries massive sulphides, associated with spheroids of pyrite.

The cross-veins found in the central orebody are uncommon in the north end. Occasional streaks of white quartz are found traversing the dark variety. In the adjacent country-rock are exposed a number of small fissure-veins, which are not known to connect with the main veins. These veinlets carry chalcopyrite, with some sphalerite and pyrite. The quartz is coarse, with strong anomalous extinction, complex outlines and abundant fluid inclusions. Some thin sections show shearing and recementation. Chlorite and calcite, of secondary appearance, are plentiful. The walls of these veins are plane and are marked by sericite seams. One veinlet noted contained angular wall-rock fragments embedded in the quartz.

Outcrop.

The north end vein-system outcrop is obscured by a mantle of detritus. The northern termination is several hundred feet south of Rocky Point. A number of prospect trenches across this outcrop show little massive quartz.
South End of Mine.

South of the granitic dike and north of the adit granodiorite there occur three veins, the relations of which are obscured by small-scale faulting (Plate V). The west vein is in part of its length a simple vein of massive quartz with some sulphides, similar in character to the central ore-body vein, but only six to twelve feet in width. At the south this vein splits into a series of stringers separated by much included country-rock, and it grades over into a zone of the country rock which is scantily mineralised and contains visible garnet, with occasional irregular quartz patches. The middle vein is much larger; it is truncated in an irregular manner by the adit granodiorite on the south, and on the north splits with a strong curvature into a set of parallel quartz stringers in more or less mineralised hornfels. The west vein is of small size, and resembles the other veins in character of filling. The east vein was stoped in part of its length into a height of over a hundred feet above the adit level; it became smaller on the upper levels. The middle vein has been mined to some extent between the adit and sixth levels, and from a shaft sunk to the eighth level.

Middle Vein.

The middle vein on the south resembles the rich-
er portions of the north end ore-body. It consists of bodies of massive quartz, sometimes with massive sulphides, containing occasional horses, sometimes with sharp walls but more often grading into the quartz by a transitional "dark quartz" phase. Considerable sections of the vein consist chiefly of this dark quartz with little recognisable country-rock. Under the microscope this dark quartz is seen to consist of dense aggregates of quartz in irregular, anhedral, somewhat elongated interlocking forms, with some traces of wavy extinction, and some fluid and solid inclusions. This dense mosaic contains single grains and aggregates of chlorite, garnet, pyrrhotite, pyrite, chalcopyrite, and magnetite; some damourite, actinolite, epidote, and calcite are present. These minerals possess a schistose arrangement. The dense mosaic described is traversed and surrounded by irregular veinlets and areas of much coarser anhedral quartz, relatively free from silicates, and without schistose arrangement. This quartz shows anomalous extinction, as if the grains are composed of smaller individuals of slightly diverse orientation, but no wavy extinction is visible. Fluid inclusions are present, but this quartz is relatively free from solid inclusions. The texture suggests that the "dark quartz" is the result of the invasion and recrystallisation of a schistose rock by siliceous solutions carrying sulphides. The contrast of the recrystallised and vein-
quartz components is distinct.

In this complex vein, traversing it in all attitudes, occur veinlets of quartz which constitute a later generation. Some of these are of coarse white quartz, often with abundant dense magnetite in patches. In thin section this quartz is seen to be of coarse grain and anhedral shape, with marked anomalous extinction and abundant minute fluid inclusions in strings. There are a few minute solid inclusions of rounded shape. Chalcopyrite and magnetite occur in small amount between quartz grains, associated with actinolite needles which penetrate the quartz, and sometimes a little calcite of secondary appearance. Cubes of pyrite occasionally occur, and are seen penetrating or embedded in the quartz. A polished surface of a magnetite aggregate showed that there is some associated chalcopyrite in smooth hook-shapes; the magnetite is almost always anhedral and is typically associated with scanty fine actinolite and chlorite. Other veinlets carry large amounts of sulphides. The massive sulphides often contain spheroidal forms of pyrite.

A crosscut on the adit or 7th level affords a good cross-section of the central part of the middle vein (Plate V). This consists of alternating bands of dense quartz and of dark schist with a few sulphide specks.
The centers of the horses are relatively unaltered, but the borders are altered to a dense garnet rock which grades into a pink fine-grained garnet-quartz zone. Small inclusions in the quartz are drawn out into pink garnet streaks parallel to the veins. The sulphides are scanty, as compared with the total mass, and occur as small specks especially on the quartz veinlet borders, though marked zonal arrangement is rare. Occasional bands up to one foot wide of coarser vitreous quartz occur; these carry more abundant sulphides, and are usually at some distance from included country-rock. The walls of this vein-system are vaguely defined, the quartz stringers becoming less common and the horses larger away from the center. Throughout this vein-system occur irregular small veinlets and patches of euhedral prismatic quartz in massive sulphides; these patches are sometimes as much as six inches in width. Occasional garnet clusters of no zonal arrangement are visible in the denser quartz. In thin section the pink garnet-quartz rocks are seen to contain plentiful chlorite wrapped around the anhedral garnet. Much of this chlorite is secondary after biotite.

**Country-rock.**

The country-rock of the south end, where fresh and at some distance from quartz, is similar to that of the central and north end ore-bodies. There has been
local alteration of several types. A marked hydrothermal alteration is found in some places adjacent to the adit granodiorite contact, and results in a softer rock with well-developed chlorite and epidote. Thin sections of the walls of the middle vein show considerable hydrothermal alteration in some places, and very little in others. The alteration noticeable in many thin sections may be described under two heads; (1) that associated with stringer mineralisation by the cross-veinlets; (2) that associated with pegmatitic veinlets genetically connected with the adit granodiorite intrusion. It is not always possible to distinguish these sources of alteration, as they are to some extent superimposed. It is not certain which is the older, but it is clear that the adit granodiorite intrusion is of later age than the consolidation of the main veins; and it is likely that the cross-veinlets were formed soon after the main veins.

The country-rock in the south end is traversed by numerous small quartz stringers which are frozen on their walls, and which resemble the filling of the main veins except that pyrite is plentiful in them and that they are often irregular in shape. Where the pyrite is present and in contact with the walls, it is associated with the development of plentiful chlorite and matted sericite, and some epidote and calcite. In some cases it forms spheroids, in the interior spaces of which the pyrite
is crystallised in dendritic forms. In other cases the sericitic alteration is absent and the pyrite occurs as interstitial aggregates of dense grain associated with chlorite, and embedded in quartz (fig. 3, Plate XII). Where the quartz is in contact with the walls, coarse garnet is locally produced. In veinlets carrying little pyrite, pyrrhotite, magnetite, chalcopyrite and sphalerite are locally abundant, and the alteration is of a type in which chlorite, epidote, and calcite are present only in small amount. Thin sections of such veinlets and the adjacent country-rock show two phases which may be present in one thin section. The country-rock phase is a mosaic of fresh calcic plagioclase, quartz, biotite, enstatite, garnet and damourite, containing some sulphides, magnetite, and tourmaline. The vein-quartz is coarser, and is relatively free from silicate minerals; it traverses and surrounds the country-rock phase, and is typically present in mineralised specimens. There is some gradation between the types of alteration characterised by fresh biotite and plagioclase feldspar on the one hand and that characterised by felted sericite and chlorite on the other. The amount of pyrite present appears to control the degree of hydrothermal alteration.

The south end country-rock is also traversed by small veinlets of pegmatitic type, which are readily re-
cognised by the coarse grain and the feldspar content. These veinlets produce an alteration in their walls characterised by abundant damourite, sericite, chlorite and epidote. They carry little or no sulphides. Accompanying the formation of these veinlets there was some shearing and compression, so that the rocks of the south end all contain small shear veinlets, often occupied by chlorite, epidote, and drag from sheared sulphide grains, cemented by secondary quartz.

An example of alteration of doubtful origin was noted in thin sections from the middle vein. This was originally vein matter composed of a country-rock phase, containing calcic plagioclase, garnet, biotite, sulphides, and magnetite, and an enclosing vein-quartz phase. The rock was then sheared and invaded by solutions which formed veinlets of biotite, associated with a large proportion of apatite and some tourmaline and quartz. The apatite and tourmaline penetrate the adjacent minerals in short and long needles. The original feldspar became densely crowded with fine apatite, abundant fluid inclusions, and what appears to have been fine biotite grains. The biotite is now altered to chlorite, and plentiful epidote is present, associated with some sulphides.

The veins of the south end do not reach the sur-
face; they have not been traced above the fifth level, and the bedrock in this neighborhood is overlain by the grey basalt sheet.

**Country-rock: General Relations.**

The openings of the Walker mine are confined almost entirely to the immediate neighborhood of the veins. The country-rock so exposed is approximately uniform in character. It is, as elsewhere described, a dense aggregate of anhedral quartz, calcic plagioclase and enstatite grains, containing abundant garnet, biotite, and magnetite in grains and aggregates, with minor amounts of damourite, tourmaline, apatite, and cyanite. Hydrothermal alteration is slight, though locally in evidence.

On the surface the relations of this rock are obscured by the overlying lava and by later intrusive action. It has been shown that the formation is probably of Jurassic age, but the age cannot be stated with certainty. The exposures from the Upper Camp to the termination of the north end orebody, near the vein, are of a rock similar to that described above, modified by weathering. To the west of this outcrop the rock has a different character. Under the microscope it is seen to have been a clastic rock formed of angular fragments of plagioclase feldspar embedded in a finer-grained matrix. The feldspar grains are now almost entirely altered to dense sericite
and epidote. The groundmass is a dense recrystallised mosaic of quartz grains containing laths of biotite and less plentiful colorless mica. Epidote is plentiful, and much of the biotite is altered to chlorite. Magnetite is disseminated throughout. There are occasional areas of coarser anhedral quartz which locally have the character of veinlets. In hand-specimen this rock contain green epidote spots.

The most easterly exposures of country-rock in the mine are in a diamond-drill cross-cut hole from the south end, and in a long hanging-wall drift north of the north end ore-body. The diamond-drill core shows a dense rock with light-colored spots, and occasional greenish epidote aggregates, at 500 ft. distance in the hanging wall. Under the microscope this rock closely resembles the rock west of the outcrop. It has the same sericitised feldspar grains, recrystallised groundmass, and later hydrothermal alteration. The epidote aggregates are also closely similar. No tourmaline was noted. In the long hanging-wall drift north of the north ore-body the rock exposed also has these epidote aggregates. Under the microscope it is seen to have been a feldspathic rock of porphyritic or poorly-sorted clastic texture. The feldspars are sericitised, and the groundmass is recrystallised to quartz and biotite. Tourmaline is abundant, and
forms "suns" of radiating needles in the altered feldspar. Some hydrothermal alteration is noticeable.

A series of thin sections of specimens from the north crest and west spur of Rocky Point show a different type of alteration. This outcrop is several hundred feet north of the end of the north ore-body. The sections show that the rocks at this point are similar to the ore-body country-rock, except that chlorite, damourite and fine sericite are extensively developed, and biotite occurs only in remnants. These rocks contain abundant tourmaline in short prisms. The rocks on the northern scarp of Rocky Point are also characterised by the strong development of damourite and chlorite, accompanied by plentiful tourmaline. Some specimens consist chiefly of damourite.

The Piute vein outcrop is composed of dense massive quartz; oxidation has removed any sulphides which may once have been present. In the Piute tunnel this quartz shows scanty blue stains, but the small amount of limonite present indicates that the copper content was small. The adjacent country rock is soft and iron-stained, and cannot have been highly siliceous. No garnets were noted. There also occur in this tunnel seams of gray sericitic schist. The highly siliceous and indurated rocks of the ridge of Rocky Point are not characteristic
of the Piute occurrence.

The data presented above may be summarised as follows. In the immediate neighborhood of the Walker ore-bodies, the country-rock is a hornfels recrystallised at high temperature, and characterised by the presence of garnet, fresh plagioclase, and fresh biotite; tourmaline is invariably present, but in small amounts, and hydrothermal alteration is slight. No trace of original structure or minerals remains, except for the occasional orientation of biotite aggregates, which may be inherited from an original schistose rock. Immediately in contact with the vein quartz, a coarser texture and more abundant garnets are frequently developed. At several hundred feet distance, both in the hanging wall and footwall, this rock gives place to rocks in which the original texture is distinctly seen, garnets are absent, and hydrothermal alteration is strong; tourmaline is locally present. To the north of the ore-bodies, on the surface, the type of rock is also different; it is characterised by the presence of abundant tourmaline and damourite, and by strong development of hydrothermal minerals.

Observation of the contacts of the granodiorite intrusives in the vicinity of Walker Mine shows that the complete recrystallisation of the adjacent sediments is confined to the immediate fringe of the contact, and
gives place to incomplete recrystallisation and marked hydrothermal alteration at a distance of one or two hundred feet. The alteration of the rocks along the Walker vein system cannot therefore be ascribed to the action of the granodiorite rocks outcropping in this district, and is to be ascribed to the agencies which formed the Walker veins.
MINERAGRAPHY OF WALKER MINE ORES.

Ore Minerals.

The principal metallic minerals of the Walker Mine ores are chalcopyrite, pyrrhotite, cubanite, and pyrite. Magnetite and sphalerite are minor constituents, and there occur small amounts of löllingite, galena, regnolite (?), tetrahedrite, stibnite, and gold.

Chalcopyrite.

The chalcopyrite is of the common variety, but possesses a faint greenish tint in some specimens. The massive mineral is composed of smooth-outlined anhedral crystals, which may be detected by the cleavage traces on imperfectly polished specimens (fig. 3, Plate XIV).

Pyrrhotite.

The pyrrhotite is the common variety, and gives the usual microchemical and other tests. The cleavage traces may be developed by polishing on a soft cloth, and in many specimens show a curly or wavy wood-grain structure.

Cubanite (chalmersite)

The cubanite (Cu Fe₂S₃) closely resembles chalcopyrite in color, but has a more creamy tint. It is slightly harder than chalcopyrite, and is much more brittle, so that it is difficult to polish. It is readily
distinguished from pyrrhotite by its lesser hardness and its negative reaction to potassium hydroxide, and from chalcopyrite by the more creamy color and slightly greater relief. The cubanite occurs in the form of oriented blades in chalcopyrite, and less commonly as irregular smooth outlined areas. Pyrrhotite is a constant associate in the Walker Mine ores. The cubanite is slightly anisotropic in polarised incident light. Between crossed nicols the blades are seen to be composites of twins; the twin face is parallel to the long dimension.

Magnetite.

The magnetite of the massive ores appears to be of the common variety. It occurs in the massive sulphides in smooth anhedral shapes (fig. 2, Plate XV), and is quite similar to the sulphides in its external relations. This original ore mineral is distinct from the magnetite produced by metamorphic processes. Four other types of magnetite may be distinguished in the rocks of the Mt. Ingalls district; (1) the original magnetite of the normal igneous rocks; (2) the secondary magnetite of the igneous rocks, produced during the alteration of original silicates to hornblende and uralite by late magmatic reactions; (3) the magnetite produced by high-temperature recrystallisation, occurring in hornfels and other rocks; (4) the secondary magnetite associated with hydrothermal
alteration minerals such as epidote, chlorite, and sericite. In the Walker ores in general three types are present, namely the high-temperature recrystallisation magnetite, associated with garnet in the vein-filling; the hydrothermal secondary magnetite associated with the alteration of the biotite, contemporary with the sulphides, to chlorite; and the original ore-mineral magnetite associated with the sulphides. These types may usually be distinguished as follows:—the high temperature recrystallisation magnetite, by the relatively coarse grain and occasional euhedral shape; the hydrothermal by-product magnetite, by the fine grain and frequent euhedral shape; and the ore-mineral magnetite, by the coarse grain and anhedral shape. The associated minerals furnish the chief distinction between these types.

The magnetite of the massive ores sometimes contains oriented inclusions of a white mineral, probably hematite (fig. 1, Plate XVIII)

Sphalerite.

Small amounts of sphalerite are characteristically present in the massive ores, in smooth anhedral grains of small size. In thin section the sphalerite is deep red and translucent, indicating that it contains much iron. Under high magnifications these grains of sphalerite are often seen to contain oriented inclusions of chalcopyrite.
Such a grain is shown in fig. 4, Plate XVII, which also shows the complex outlines sometimes noticed; the smooth outlines (fig. 3, Plate XVII) are more common.

Pyrite.

The pyrite in the Walker Mine ores is of the common mineral type. Occasional specimens of good crystals (cubes or pyritohedrons) are reported from the ore, but the usual occurrence is in dense masses, irregular grains, or spheroidal forms.

Löllingite.

The mineral here described as löllingite occurs in such fine forms in the ore, that qualitative chemical tests were not feasible, and the composition of this mineral is not certainly known. It is a tin-white mineral, harder than pyrrhotite but softer than arsenopyrite; it takes a high polish with the usual polishing agents, and assumes high relief in polished surfaces. Microchemically, it differs from arsenopyrite in its negative reaction with nitric acid. It is not affected by the other reagents of the system of Davy and Farmham. It occurs as prisms, rhombs, and less regular forms, resembling those of arsenopyrite, and occurs invariably in euhedral or subhedral crystals.

This mineral is anisotropic in polarised incident light. Between crossed nicols many of the prisms
are seen to consist of polysynthetic twins; the twin plane is parallel to the long dimension. The interference colors are greenish and reddish. These characters agree with those described by Schneiderhoehn\(^4\) for arsenopyrite. The mineral is probably l"ullingite, which resembles arsenopyrite in crystal habit.

**Galena.**

The galena of Walker Mine yields all the usual microchemical tests and in the rare hand-specimens it has the characteristic perfect cubic cleavage and softness. Before the blowpipe it gives a lead bead and an odor of sulphur dioxide. It lacks however the tin-white color of pure galena. In polished surfaces it has a grayish white color, somewhat lighter than that of tetrahedrite. It may contain impurities such as antimony or arsenic.

**Regnolite(?)**

The mineral described under this name is grayish white under the microscope, soft, brittle, and reacts negatively to all the reagents of the system of Davy and Farnham\(^3\). The color is lighter than that of tetrahedrite and slightly more dark than that of the impure galena. It occurs in intimate intergrowth with other minerals, especially galena and tetrahedrite, and qualitative chemical tests were not feasible. Regnolite
(Cu₇As₂S₁₂) is the only mineral described by Davy and Farnham which possesses these properties; Murdoch has described specimens of argentiferous jamesonite which have somewhat similar properties.

Between crossed nicols this mineral shows a banding which may be due to polysynthetic twinning, but the anisotropism is weak.

**Tetrahedrite.**

The tetrahedrite is of the common variety. When covered with nitric acid some specimens develop a brown tarnish in spots and streaks, while the remainder of the mineral remains unaffected. This may indicate a small localised content of silver.

**Stibnite.**

The stibnite yields all the usual tests. Much of this mineral occurs in small euhedral crystals, and is apparently pure. It is markedly anisotropic, and between crossed nicols the grains appear to be homogeneous.

**Gold.**

Small amounts of metallic gold were noted in some specimens, associated with tetrahedrite and galena, in small grains of smooth outline. The color, sectility, and extreme softness are characteristic.

**Texture of the Ores.**

As described elsewhere, the greater part of the filling of the Walker veins consists of quartz carrying
aggregates of sulphides, magnetite, and associated gangue minerals (biotite, chlorite, actinolite, quartz, epidote and calcite), which seem to be contemporary minerals, and later than the quartz of the vein. For convenience, the latter gangue minerals will be referred to as the "second generation gangue". A thin section of typical quartz ore is shown in fig. 1, Plate XII. In polished surfaces the distinction between the two kinds of gangue becomes manifest. The sulphide grains appear to possess interstitial character, and are embayed by the smoothly anhedral grains of the enclosing vein quartz. In the sulphides the second generation gangue is much more complex and irregular in character, (fig. 4, Plate XV) and encloses abundant grains of the sulphides; while the chlorite, actinolite, etc. of the finer gangue frequently penetrates the vein quartz (fig. 3, Plate XV). Where the sulphides and the vein quartz are approximately equal in amount, and where second-generation gangue is not abundant, the vein-quartz assumes smooth rounded and subhedral forms in the sulphides (fig. 1 and 2, Plate XV); while in massive sulphides grains of vein quartz are frequently well formed (fig. 2, Plate XVI).

In some portions of the central ore-body there occur types of massive ore in which the second generation gangue is abundant. Fig. 1, Plate XVI shows a specimen
of this kind, in which quartz and some calcite are the chief gangue minerals. The complexity of the gangue boundaries, even under high magnification, is clearly seen.

Most of the more massive ore specimens, however, contain little contemporary gangue. They are composed chiefly of chalcopyrite, with islands and areas of pyrrhotite, which present smooth undulating outlines to the chalcopyrite; in the chalcopyrite occur oriented blades of cubanite. Under high powers small amounts of magnetite and sphalerite are generally seen in small anhedral grains; small crystals of löllingite are occasionally present, and small irregular pyrite grains are common. Figures 2 and 3, Plate XVI, are examples of this common type.

Occurrence of Pyrite.

In some specimens there occur nodules of dense pyrite, with concentric structure, in pyrrhotite (fig. 4, Plate XVI). In many specimens of massive ores, pyrite is present only in small irregular grains. In other specimens it occurs in spheroidal forms up to two inches in diameter, embedded in chalcopyrite. These are composed of dense pyrite, and contain a central space into which project ribs of dense pyrite encrusted with pyrite crystals; the crystal form is the octahedron, usually modified by the cube. The shell is not continuous, but is perforated
by openings continuous with the central space. In a few cases the cavity is partly filled by dense quartz with some calcite, but usually the space is void. The spheroidal form is preserved by the concavities in the enclosing chalcopyrite, against the openings in the shell. The outlines of these spheroids are generally smooth, but often contain irregular indentations. In some cases the pyrite forms are connected with strings of irregular pyrite grains traversing the enclosing sulphides. These pyritic forms usually contain small areas of chalcopyrite, pyrrhotite and sphalerite (fig. 3, Plate XVII).

Where the pyrite occurs in small grains it is usually found adjacent to gangue, such as chlorite or quartz; the gangue may be either the smooth-outlined vein-quartz or the second-generation gangue. When it occurs as fairly large grains, it is characterised by the spheroidal habit, and is commonly found in dendritic forms associated with open cavities (fig. 1, Plate XVII). These open cavities are almost invariably present. The size of the encrusting pyrite crystals varies from 1mm diameter down to very fine sizes. Figure 2, Plate XVII, shows a cross-section of a crystal-encrusted rib.

Pyrite also occurs as dense aggregates of interstitial shape, associated with chlorite, in quartz veinlets in the south end country-rock (fig. 3, Plate XII).
Intergrowth structures.

The types of ore described above constitute the important ores of the Walker Mine. There occur also, in the central portion of the central ore-body, certain types of ore in which the less common minerals löllingite, galena, regnolite, tetrahedrite, and stibnite are especially concentrated. These ores are of interest on account of the development of complex intergrowth or graphic structures in them, though they contributed little to the output of the mine. They are characterised by the presence of well-formed red garnets; the more massive sulphides contain plentiful second generation gangue, especially biotite.

In these ores there are developed intricate intergrowth structures of löllingite in chalcopyrite. Under high magnifications a gray mineral, probably sphalerite, is seen to be characteristically present (fig. 1, Plate XIX). The löllingite is invariably in subhedral forms. The grains vary in size from particles scarcely visible under the microscope to grains 0.2mm in diameter. Under the highest magnifications minute particles, probably of löllingite, are seen disseminated in the chalcopyrite between the larger grains. Occasionally other minerals, such as galena, tetrahedrite, and regnolite, form a part of the intergrowth structure
These intergrowth structures possess some striking features. In a given two-component intergrowth structure area, the percentage of the components is usually constant, as far as can be judged by the eye, regardless of the grain-size developed; in the three-component intergrowth structures the ratio of the components is constant only in small areas, but still seems to be independent of grain-size, where different grain sizes are developed. Fig. 2, Plate XIX, will illustrate this point. The percentage of löllingite, galena, and chalcopyrite in the coarsest-grained area may be noted under low magnifications; if successively higher magnifications are applied to the finer-grained intergrowth structures shown in the photograph, approximately the same proportions are found. On the other hand, in similar intergrowths in other parts of the same specimen, the percentage of galena varies indefinitely; but the ratio of löllingite to the groundmass remains approximately the same.

These intergrowth structures, which possess a certain uniformity of composition within themselves, possess some of the characters of independent minerals. Thus intergrowth structure areas of löllingite and chalcopyrite, occurring in chalcopyrite, present sharp out-
lines to the enclosing sulphide (fig. 2, Plate XVIII). The variation in grain size within the intergrowth structure is especially marked on its borders, where usually a coarse grain is found. The sharpness of the outline is due in part to the fact that these border crystals of löllingite are often oriented with their outer edges in a line.

These intergrowth structures usually occur adjacent to the second generation gangue (fig. 2, Plate XVIII). In the vicinity of gangue the uniformity of the structure is lost. The löllingite tends to cluster or deposit on the near-by quartz, and sometimes forms relatively large crystals. The formation of such clusters or crystals seems invariably to be accompanied by a reduction in the amount of löllingite in the surrounding chalcopyrite (fig. 4, Plate XVIII).

A specimen of massive galena and chalcopyrite (figs. 3 and 4, Plate XIX) shows a galena-tetrahedrite-chalcopyrite complex in contact with chalcopyrite free from these minerals. The contact is sharp, and is continued in a sharp line by the galena, the terahedrite, and by the löllingite-chalcopyrite intergrowth structures; the intergrowth structures have sharp contacts also against the tetrahedrite and galena. The photographs also show the well-formed quartz and garnet in the galena.
In hand specimens almost perfect crystals of these minerals may be seen. The galena in this specimen carries a little stibnite in minute grains.

In other massive specimens, composed chiefly of galena and regnolite(?) with some lollingite, stibnite, and tetrahedrite, further intergrowth structures are well developed. The regnolite and galena form typical graphic intergrowths, in which stibnite is uniformly disseminated. The regnolite is somewhat more abundant than the galena, and forms the continuous phase of the intergrowth structure; areas of galena-free regnolite occur, which are also quite free from stibnite (fig. 1 and 2, Plate XX). The stibnite is often euhedral. These intergrowth structures are remarkably constant in composition, regardless of the notable variation in the size of the grains. The specimen is composed of numerous small areas, of somewhat indistinct outline, within which there is a roughly parallel orientation (fig. 4, Plate XX). Grains of lollingite are irregularly distributed throughout.

In another specimen is seen an intergrowth structure of galena and regnolite(?), in which stibnite is absent, but in which the galena-regnolite ratio is approximately the same. The intergrowth-grain structure and orientation is clearly brought out by the contrast in coarseness of the components (fig. 3, Plate XX).
The relation of the lilllingite grains to the galena and regnolite appears to be accidental, but in some specimens the lilllingite assumes an intergrowth arrangement in tetrahedrite. Tetrahedrite grains in the galena-regnolite structures are usually bordered by a "beach" of minute lilllingite grains. Larger grains of lilllingite are frequently developed, around which the minute grains are correspondingly fewer. (fig. 1, Plate XXI). In massive tetrahedrite there occasionally occur abundant minute lilllingite prisms in oriented arrangement (fig. 2, Plate XXI). Galena sometimes forms part of this intergrowth (fig. 3, Plate XXI). Chalcopyrite is also occasionally present.

These intergrowths occur more commonly as small grains in quartz than as hand-specimens, in the central ore-body. The study of these grains shows a great variety of sulphide textures. As before stated, the grains usually possess interstitial character in the vein quartz, occasionally modified by the penetration of the quartz by the second generation gangue. Many of the specimens show evidences of movement and fracturing prior to the final consolidation of the sulphides, in that the sulphides often occur as fillings in fracture cracks connecting the larger interstitial grains (fig. 1, Plate XXII). The smoothness of the grain outlines is of course a function of the grain-size and the magnification employed.
Fig. 2, Plate XXII, is a photograph of a relatively large grain under low magnification, and presents a complex appearance. Study of such specimens, under higher magnifications, suggest that the dissected appearance of the vein-quartz is due to movement and fracturing, while the sulphides were in a condition to flow under pressure.

The composition of the individual grains varies between wide limits, and the type of intergrowth structures found differ correspondingly. Fig. 3, Plate XXII, shows a grain of galena and regnolite with fairly uniform intergrowth structure. In other grains the textures are more complex. The component minerals of a grain generally occur in separate, relatively large areas at the ends or sides of a grain, separated by intergrowth structures of finer grain (fig. 3, Plate XXII).

Löllingite occurs frequently in these grains, usually in intergrowth structures in chalcopyrite. Triple intergrowth structures, of löllingite and chalcopyrite in a continuous phase of galena, sometimes occur (fig. 4, Plate XXI; fig. 1, Plate XXIII). In rare cases löllingite-chalcopyrite structures form an independent phase, which is graphically intergrown with galena. Fig. 2, Plate XXII, shows such structure. Fig. 3, Plate XXII, shows a similar structure, in which the löllingite occurs in coarser crystals.
The löllingite in these ores does not conform to the smooth outlines of the vein-quartz and second generation biotite as do the other minerals. It frequently penetrates both biotite and quartz, but never to a greater distance than half the length of the rhomb-shaped crystals. (fig. 4, Plate XXIII).
VI

PETROGRAPHIC NOTES:
MICROSCOPIC CHARACTERS OF THE QUARTZ.

The quartz occurrences in the Mt. Ingalls district show a variety of microscopic characters, which are to some extent indicative of the history of the rocks in which the quartz occurs. In view of the importance of these characters as criteria of rock history, they were observed in detail; and although the meaning of these characters is not well understood, it is possible to draw some conclusions by analogy between the characters of quartz of known history and those of quartz in rocks of doubtful history. For these reasons the characters of the different types of quartz will be briefly recorded.

Igneous phenocryst quartz.

Examples of this type occur in the Curtner quartz diorite porphyry. The phenocrysts are euhedral, sometimes imperfectly so, and are embedded in a dense feldspathic groundmass. They are somewhat corroded by the epidote of the later hydrothermal alteration. This quartz was evidently formed at high temperatures, and is contemporary with the andesine of the other phenocrysts. It is apparently homogeneous and exhibits no extinction anomalies.
Interstitial igneous quartz.

The quartz of the granodiorite rocks is invariably interstitial in occurrence. The outlines are anhedral to other quartz grains and the quartz is moulded on the feldspar, biotite, and hornblende. This quartz shows anomalous extinction in nearly all grains (fig. 4, Plate IX). In nearly all positions, the grains appear to be homogeneous; near extinction, however, they are seen to be composed of smaller individuals, of slightly different orientation, within which the extinction is uniform. The granodiorite rocks invariably show the effects of some hydrothermal alteration, with the production of epidote, chlorite, sericite, and calcite. These minerals appear to be later than the quartz, which is itself later than the feldspar and feric phenocrysts. It is not certain, therefore, that this quartz was formed above 575°C (the inversion point); it may equally well have consolidated at a somewhat lower temperature. It contains plentiful minute fluid inclusions with gas bubbles.

The anomalous extinction is more coarsely developed, and is more readily seen, in large than in small grains; in the comparatively large quartz grains of the granitic dike, Walker Mine, the anomaly is often well developed.

The quartz grains of the interstitial complex in the adit granodiorite and granitic dikes, Walker Mine,
are too small to show the internal structure.

**Pegmatitic quartz.**

The quartz of the pegmatites, aplites, and of the quartz-rich veinlets associated with tourmaline and molybdenite, is usually coarse-grained, and almost invariably shows extinction anomalies similar to those described in the interstitial igneous quartz, but developed on a larger scale. These veinlets show the effects of strong hydrothermal alteration, of later age than the quartz. It is generally accepted that the quartz of these types of veinlets has formed below the inversion point (575°C). This coarse quartz contains abundant and relatively large fluid inclusions with mobile gas bubbles. The external form of the grains is anhedral, and occasionally highly complex, the adjacent grains interlocking in seams of elaborate hook-shapes along their boundaries.

**Hydrothermal fissure-vein quartz.**

Thin sections of the small fissure-veins occurring in this district show them to be composed of anhedral quartz grains. The arrangement on the walls is an imperfect comb-structure, and the centers of the veinlets are composed of elongated grains in parallel or irregular arrangement. These grains are usually composed of roughly parallel laths, sometimes diverging in fan-shapes, which extinguish in sequence. This is probably
a variety of the "flamboyant" structure described by Lindgren. This quartz contains a few fluid inclusions. 

**Dynamo-metamorphosed quartz.**

The schistose sediments of the Carboniferous formations contain clastic quartz grains which form the centers of miniature augen in shale rocks and which compose the major part of the siliceous sediments. These grains, when rotated between crossed nicols, show a dark extinction band which moves from one side of the grain to the other; in the central position the darkness of the extinction band shades off uniformly to the edges of the grain. In many grains the opposite sides of the grain apart extinguish in directions up to 45°. This wavy extinction, or undulatory polarisation, is found also in the quartz of the Gruss veins. In these veins the effects of shearing and compression are manifest in the brecciated character of the quartz; the fragments are cemented by quartz of a later generation.

**Quartz of the contact-metamorphosed rocks.**

The quartz of the recrystallised rocks adjacent to the granitic intrusives of the district usually exhibits no observable anomalies. The grains are probably too small to show the type of anomalous extinction which characterises the pegmatitic quartz. They show no distinct wavy extinction, although this anomaly is mani-
fest in the equally small grains of the Carboniferous schistose rocks. They contain few fluid inclusions, but usually enclose abundant fine inclusions of biotite and other minerals.

The quartz of the irregular veinlets which traverse the contact-metamorphosed rocks shows anomalous extinction, in the larger grains. In specimens from some localities wavy extinction may be distinguished, but this appears to be exceptional.

**Fluid and gas inclusions.**

The fluid inclusions referred to above occur in cavities of wholly irregular outline, sometimes isolated but more often lying in continuous straight or curved planes in the quartz. In cross-section these appear as strings which traverse the quartz, often from grain to grain, and which appear to be independent of the internal structure of the grains. No solid bodies were observed in these cavities. Many if not all of these fluid inclusions contain mobile bubbles of gas. These bubbles do not disappear when warmed above 40°C, the critical temperature of carbon dioxide; the fluid is therefore not liquid carbon dioxide, and is probably an aqueous solution. The fluid inclusions are small; they are visible under a magnification of 400 diameters. Under a magnification of 1600 diameters they are clearly visible, and the
Brownian motion of the smaller gas bubbles may be distinctly seen.

Quartz of the Walker Mine.

The vein quartz of the Walker Mine ores possesses the anomalous extinction of the granodiorite quartz, and shows no distinct wavy extinction. It contains plentiful fluid inclusions. The outlines are anhedral, occasionally complex. In the coarser quartz of the cross veins and white-quartz bodies the anomalous extinction is well-developed, and complex outlines are more common. Evidences of microscopic shearing are absent, except in some localities in the south end, and in the hydrothermal fissure veinlets in the north end.

In some places, for example near the dense quartz diorite dike, the quartz of the country-rock shows distinct wavy extinction, but such effects are localised. In the country-rock phase of the "dark quartz" elsewhere described, the quartz is in somewhat elongated grains, in indistinct schistose arrangement; in some thin sections it shows feeble wavy extinction. Distinct wavy extinction was not observed in this type of quartz.

History of the Walker Mine quartz.

It may be concluded, from the data and comparisons presented above, that the Walker Mine main vein quartz is of the same type as that of the granodiorites.
It differs from that of the local pegmatites in its finer grain, and in the much weaker hydrothermal alteration with which it is associated. In these respects it differs also from the cross-veinlets which occur in it and from the hydrothermal fissure-veinlets of the region. The quartz of the country-rock is similar in general to that of the contact-metamorphosed rocks of the district. Since the formation of the veins, the quartz and the country-rock have suffered no important dynamo-metamorphism.
Hypotheses of Ore-Deposition.

There are two principal hypotheses regarding the formation of vein deposits. The older of these is the theory that such ores are deposited by attenuated aqueous solutions of the ore minerals and gangue, either by simple deposition in open fissures, or by metasomatic replacement of the host rocks. This hypothesis is developed from the known ore-forming power of hot spring waters, both by the precipitation of the dissolved constituents, and by replacement in adjacent rocks. It has received elaborate development from the point of view of the microscopic and megascopic textures of ore minerals, gangue, and country rock, at the hands of numerous investigators. A detailed exposition of this hypothesis is given in the textbook on "Mineral Deposits" by Lindgren. The source of these ore-forming solutions is held to lie in the igneous rock magmas, which contain notable amounts of water; this water, together with the ore and gangue substances, is expelled during the consolidation of the magma, and, with some admixture of meteoric waters, rises through channels in the superjacent rocks,
depositing the load of ore and gangue substances as conditions compel. Where the solutions permeate and traverse favorable rocks, there is sometimes a simultaneous solution of the rock minerals, and deposition of substances originally in solution, without change in rock volume. The dissolved rock minerals are removed in solution. This gives rise to "replacement deposits", and various rock-alterations. Changes in solutions traversing channels of ore deposition produce changes in the ores and gangue already deposited, giving rise to the complex textures often found in gangue and sulphide ores.

From the standpoint of physical chemistry, these solutions are fluid and possess small viscosity. They are held to contain dissolved bases and alkaline sulphides and carbonates, besides gangue and ore substances in dilute true solution and colloidal dispersion. The existence of the colloidal state is doubtful above 364°C, the critical point of water. Physically, the solutions rise under the hydrostatic pressure of their dissolved gases; the total volume of solution required to produce an ore-deposit is many times greater than the volume of the minerals deposited.

Later work on the origin of hot springs has emphasised the importance of meteoric waters in their formation. Lindgren, in a recent editorial, has summarised
this evidence and concludes that the assumption of large volumes of water of igneous origin is of doubtful admissibility.

The other principal hypothesis of ore-deposition is that of origin by the injection, under magmatic or "intratelluric" pressure, of relatively concentrated and viscous magmatic differentiates containing ore and gangue substances, into fissures or zones of weakness in the superjacent rocks. The principal exponent of this view is J.E. Spurr, who applies the name "ore-magma" to the injected substances, and the name "veindike" to tabular ore-bodies so formed. This hypothesis emphasises the analogy of certain types of magmatic differentiates (e.g. pegmatites) to ore-deposits, and the gradation of admittedly "injected" differentiates into quartz-veins indistinguishable from ore-veins. A considerable body of field evidence is brought forward to support the contention that many ore-deposits were introduced in a viscous condition, but this evidence is otherwise explained by advocates of the other hypothesis.

From the standpoint of physical chemistry, Spurr is non-committal as to the precise characteristics of his "ore-magmas", but inclines to the view that their viscosity is due to the presence of the ore and gangue substances in the colloidal state, with a relatively small
amount of water. However, he uses the term "magma" in the etymological sense, and his "ore-magma" is any complex which deposits or becomes an ore-body, whether analogous to an igneous rock magma or not. Thus he includes in his system the attenuated solutions which deposit ore near the surface, and for which he does not claim a high degree of viscosity.

The injection theory of ore-formation has not received the elaborate petrographic and mineragraphic development which the attenuated-solution theory has received. It is evident that the textures of an ore-body formed by the consolidation in place of a viscous inject must be interpreted in a different manner to those of an ore-body through which solutions have constantly passed. Petrographically, the wall-rock alterations adjacent to an injected ore-body must be in some degree analogous to those adjacent to igneous rock intrusions, especially pegmatites and similar differentiates; and the sequence of changes within the ore-body must be somewhat analogous to the processes which take place during the later stages of consolidation of igneous rocks. These differences of interpretation are not merely academic questions, but have a profound economic importance; for if the texture in question is due to a change in passing solutions, these solutions may have taken a different path from those
which formed the earlier ore, and the occurrence of the later minerals may have a different configuration from that of the earlier minerals; it may be controlled by later fissures, for example; while if the texture is due to differential consolidation, the later minerals will be later in consolidation but contemporary in introduction, and will occur only in association with the earlier minerals.

The outstanding difficulty in the acceptance of the injection theory lies in the explanation of the physical chemistry of the viscous injects. The viscosity of igneous magmas is held to be due to "aqueo-igneous fusion", the constituents in which are held in mutual solution by high temperature and pressure, and by the presence of substances which lower the melting point, such as boron, fluorine, and water. This state is supposed to persist in the pegmatites and aplites. The quartz vein magmas are supposed to owe their viscosity to the presence of much colloidal matter; but the stability of hydrophile colloids persists above the critical temperature of water (364°C) is doubted by some authors. There is here a hiatus, concerning which Spurr is silent. Merritt holds that pegmatites and ore veins are deposited as gels.

To obtain some light on the point, a search of the literature on colloid chemistry was made. No evidence
was found in the literature that hydrophilic colloids are unstable above 364°C. The chief points disclosed are:

(1) this temperature is defined as the critical point of water, only in the absence of surface and adsorption phenomena; and since these phenomena dominate the physics of the colloidal state, the temperature cited does not apply to the water of hydrophilic colloids;

(2) experiments on the adsorption of carbon dioxide by silica gel show that the critical temperature is raised in the pores of the adsorbent;

(3) some water still remains adsorbed in silica gels heated to 600°C;

(4) though increase in temperature tends to dehydrate hydrophilic colloids, increase in pressure counteracts this effect;

(5) the volume of a hydrophilic colloid is less than that of an equal weight of solid substance and water separately; therefore, according to the laws of Van't Hoff and LeChatelier, under high pressures the colloidal state is more stable than the non-colloidal state, and tends to form from the non-colloidal state. It is a curious fact, that the chief oxide constituents of magmas are either prone to assume the colloidal state, as are silica and the amphoteric oxides of iron and aluminum, or are soluble in water, as are the oxides of the alkalies and alkaline earths; while the sulphides are prone to assume the colloidal state in the presence of hydrogen sulphide under pressure. It is known that the rapidly cooled magmas form glasses. Ex-
Experiments on common glass show that it readily assumes the colloidal state when digested with water under pressure. It seems not impossible, therefore, that the colloidal state is present in the "aqueo-igneous fusions" of the igneous magmas. The transition from the viscous igneous magmas to viscous quartz and sulphide magmas, and finally to attenuated solutions and hot springs, becomes comprehensible under such an assumption.

The chief differences in the two theories outlined above are as follows: (1) the injection theory demands much less water than the attenuated-solution theory. The original ore-content of an igneous magma may be segregated and injected into the superjacent rocks without wide diffusion; thus highly localised small segregates may form highly localised small ore-bodies. It would seem that ore-bodies formed by dilute solutions must have derived their ore content from larger bodies of rock, and must have deposited their burden over wider areas with concomitant more extensive alteration. (2) An injected ore-magma may open its own fissures, whereas dilute solutions are restricted to openings already open. (3) Differentiation may take place in a consolidating ore-magma as in an igneous rock magma. This is not possible in an ore-body deposited by dilute solutions. (4) Viscous injects may support and carry fragments of country-rock
which would sink in dilute solutions. Mode of Criteria of Ore Genesis.

It seems impossible to state with certainty whether any particular vein-deposit has been formed by dilute solutions or by injected viscous "ore-magmas". The exponents of the dilute solution theory have exercised much ingenuity in explaining, on this basis, the great mass of data which they have been largely instrumental in collecting regarding the features of ore-deposits. All known megascopic and microscopic features of ore-deposits may be explained by a sufficient number of depositions and replacements, by a sufficient number of changing solutions, which having done their work have vanished, leaving no other trace of their passage. In attempting to explain the genesis of the ores of the Mt. Ingalls district, it is certain that the dilute solution theory cannot be ignored. These ores may well have been formed by such processes, but it will be of greater interest to develop an explanation of their features on the basis of the injection theory. This newer theory is as yet relatively undeveloped; its application to the problem of the ores of Mt. Ingalls district necessitates some modifications. The elaboration of such a hypothesis may contribute to the hypotheses now available on the genesis of ore-deposits.
Genesis of the Walker Mine Ores.

The Walker veins antecede the intrusive plutonic rocks of the vicinity, but are not older than the general epoch of granodiorite intrusion of the Sierra Nevada; they are therefore of Upper Jurassic or Lower Cretaceous age. They occur in sedimentary rocks which are probably of Jurassic age. Since their formation they have suffered very little metamorphism; they have merely been uplifted and eroded, with accompanying formation of faults and joints. Erosion has kept pace with weathering, and the effects of weathering are confined to a depth of fifty to a hundred feet from the surface, except along faults.

The veins were probably formed by the differentiation in an underlying granodiorite reservoir of a residual magma composed chiefly of silica, with minor amounts of iron, potash, boron, and other substances, and notable amounts of sulphides; this differentiate was injected into a belt of weakness in the superjacent sediments, probably a direction of schistosity. It was under great pressure and at a temperature probably exceeding 4000°C. The viscous mass forced its way into the laminae of the schist, forming several large irregularly lenticular bodies, containing detached masses of schist, accompanied by parallel smaller masses on the hanging and foot walls. At the same time minute veinlets of the
magma were forced into cracks in the schist, and the schist, held at a high temperature and invaded by the more volatile constituents of the magma, suffered partial solution and perhaps partial peptisation of its minerals. It lost part of its rigidity, and under the slow movement of the mass all angular outlines were drawn out. The dissolved or peptised minerals began to crystallise out in new, high-temperature minerals; as these crystals grew, the undissolved minerals, unstable under these conditions, dissolved or were peptised, and were deposited in new combinations on the already formed crystals. Though not entirely rigid, the schist masses remained intact, and preserved sharp boundaries against the invading magma. In this manner the schist commenced to recrystallise under contact metamorphism by the intrusive quartz vein magma; and as the quartz vein magma slowly cooled, or more probably as the pressure decreased owing to the escape of the gases, or diffusion and penetration of water solutions into the schist, the main quartz began to crystallise out; and in time almost the entire mass was solid.

Zonal Alteration of the Schist.

The schist nearest the quartz magma suffered the highest temperature, and more complete access of gases and solutions; it developed a coarser grain, and
greater development of garnet. In the interior of included masses, and in the walls, the grain developed was finer, and garnets were less abundantly formed. The invading veinlets had carried some sulphides; these remained plastic or unconsolidated till the last, and were stranded as isolated blebs in the crystallising schist, finally consolidating in interstitial forms. Small fragments of schist, detached in the quartz magma, were most strongly altered, and became garnet-biotite-quartz streaks. Where the penetration of schist by quartz magma was most complete, the embedded schist fragments recrystallised to highly siliceous areas surrounded and penetrated by vein quartz, but did not lose their identity; this formed the "dark quartz" transitional between vein and hornfels in some localities.

The total effects of the contact metamorphism of the schist diminished away from the injected magma on both foot and hanging wall; and at a distance of 500 ft. or so, no garnets were produced, and recrystallisation was less complete.

Cross-veins.

The quartz magma suffered differentiation within itself; the portions nearest to schist consolidated first, and those most remote from schist consolidated last. As the amount of magma solidified increased, the amount of water in the remainder increased; and the sul-
phides and the barite present tended to accumulate in the unconsolidated residue. When most of the ore-body was solid, it was fissured; and into these fissures flowed some of the unconsolidated aqueous quartz and sulphides, and barite veinlets were also formed. The widest parts of the vein, which were at the same time most free from schist masses, became richest in sulphides, and consolidated last; and in the sulphides themselves those of the lowest consolidation temperature (galena, etc.) were partially segregated, and solidified last of all.

Behavior of Tourmaline.

The Walker veins contain small amounts of tourmaline, and a little tourmaline is found in the adjacent rocks. The tourmaline is probably a late mineral; it is found in the vein matter as anhedral forms enveloping sulphides, and as good prisms penetrating and embedded in the quartz. In the hornfels it occurs in good prisms penetrating and embedded in the other minerals; in the partially recrystallised rocks it occurs as "suns" of needles in sericitised feldspar. In these rocks damourite is present in small amounts. In the rocks to the north of the north end tourmaline is plentiful, and these rocks contain much damourite and biotite (now chlorite). It seems likely that the tourmaline is a migratory mineral, associated with the residual and most fluid part of the magma. It antecedes the hydrothermal alteration, is con-
temporary with biotite and damourite, and is later than garnet, enstatite, feldspar, and the earlier quartz. It is not certain that its chemical components play a significant part in damouritic alteration, or in rendering its solutions more fluid; it may be merely an inactive associate.

Hydrothermal Alteration.

The Walker veins show the effect of fairly uniform and consistent hydrothermal alteration. The original biotite is nearly all changed to chlorite, in the quartz which contained relatively small amounts of biotite; in the larger masses of biotite associated with more massive sulphides there is only partial alteration; and in the hornfels, in which biotite is plentiful, the alteration is slight. In the country-rock phase of the "dark quartz" only chlorite is found, and no trace of biotite remains. This general hydrothermal alteration, uniform in total amount, is probably the work of residual consolidation water, and is analogous to the partial alteration which characterises the plutonic rocks of the district. The cross-veinlets are accompanied by much stronger alteration, probably analogous to the strong alteration which is associated with the small pegmatite dikes of the district; the final segregates contain more water than the main mass of the rock from which they have differentiated.
The rocks north of the north ore-body, on the surface, show strong hydrothermal alteration, as do the partially recrystallised rocks at some distance from the veins. It is probable that "hydrothermal alteration" has an upper limit of temperature, and that the vein magma lost most of its water at a temperature above this limit. When this water had penetrated some distance from the vein it probably passed below this temperature, and correspondingly affected the enclosing rocks.

Behavior of the Sulphides.

The sulphides probably remained in a plastic, unconsolidated or partly consolidated condition until the main quartz had become solid. Recent experiments have shown that cubanite separates from its solid solution in chalcopyrite only at temperatures above 400°C. Before the magma had cooled down to this temperature, according to this criterion, the pyrrhotite, cubanite, and chalcopyrite had consolidated. This criterion is vitiated by the uncertainty as to the physical condition of the chalcopyrite; the experimental work was done on solid sulphides, while the sulphides of the Walker ores may have been in a condition of dense colloidal aggregation under which conditions the unmixing point of cubanite may be lower. It seems clear that the biotite which was intimately associated with the sulphides crystallised
first, while the remaining second-generation gangue crystallised at a time when the sulphides were almost solid, or were completely solidified. It is probable also that the chalcopyrite solidified at a temperature below that of the formation of damourite and tourmaline, but above that at which hydrothermal alteration set in.

At or below the consolidation point of the sulphides, some of the sulphides were in the condition of solid solutions, or heterogeneous colloidal aggregates, of the sulphides and sulpho-salts of various metals. These mixtures or solutions became unstable at a still lower temperature, and more stable compounds separated out, with the production of the variety of intergrowths described elsewhere. The mineral lällingite alone appears to have formed at a temperature above that of the consolidation of the vein quartz; the remainder are interstitial in character. Before the sulphides were entirely solid, the enclosing quartz suffered slight local shearing, with the formation of small cracks into which the sulphides flowed.

The pyrite behaved in a manner markedly different from the behavior of the other sulphides. Together with calcite and silica or perhaps merely water and hydrogen sulphide, it separated early into immiscible viscous masses, which under the hydrostatic pressure of chalcopyrite assumed spheroidal form, either embedded in
chalcopyrite or preferentially adhering to and enclosing grains of gangue. These spheroids entrapped and contained small amounts of pyrrhotite, cubanite, chalcopyrite, and sphalerite, and were probably formed at an early stage. The consolidation of the surrounding sulphides took place, and then the pyrite crystallised in the spheroidal chambers in dendritic forms. The associated substances have since been removed, leaving the characteristic voids in these pyritic occurrences. Minute grains of pyrite, left enclosed in the other sulphides, assumed irregular forms; and some of the pyrite seems to have migrated at a late stage to form strings of minute irregular grains in the other sulphides.

The formation of the Walker veins was followed by the intrusion of the adit granodiorite and granitic dike, which truncated and intersected the veins, produced a small amount of localised shearing and alteration, and intruded a few small pegmatitic veinlets into the hornfels.

Remarks.

The theory of genesis outlined above differs radically from the usual explanation of such deposits, namely, by the metasomatic replacement of selected horizons by invading and passing dilute solutions. It offers a simple explanation of the peculiar features of the Walker veins; and, though based on assumptions of physical-
chemical processes which are not certainly admissible, it is supported by detailed study of the differentiation and alteration habit of the known igneous rocks in the vicinity. The following points favor this view:

(1) The veins proper are true quartz bodies, and show no evidence of being replacements of other rocks. Though Lindgren\(^4\) considers that such veins may be formed by replacement without leaving traces of the process, this is denied by Spurr\(^5\).

(2) The contact between quartz and hornfels is sharp and distinct, even in the partly-absorbed hornfels of the "dark quartz".

(3) The shape of the veins does not indicate selective replacement of favorable beds, but is the characteristic lenticular form assumed, for instance, by pegmatites.

(4) The veins have contact-metamorphosed the wall-rocks, and this alteration cannot be ascribed to the plutonic rocks in the district. It is markedly localised along the veins, and diminishes away from the veins.

(5) The relation of the sulphides and second-generation gangue to the vein quartz is analogous to that of the concentration residuum in the granitic dike and adit granodiorite to the first-formed quartz in those rocks. The association of sulphides with such residua has been noted by Colony\(^7\), and is exemplified in the occurrences of
sulphides in the pegmatite veinlet in the granitic dike on the adit level.

(6) Close study of the textures of the sulphides gives strong support to the theory of their origin, not by successive replacements, but by unmixing of solid solutions, or segregation of the components of original mixtures. This view of the origin of these textures has been advanced by Schneiderhoehn⁴, and accepted by Van der Ween⁵. Experimental work by Wandke⁶ and Schwartz¹⁶ has confirmed the possibility of such "unmixing".

(7) Observation of the white quartz bodies and cross-veins in the ore-bodies leads to the conclusion that they are genetically connected with the veins, and are due to differentiation of the vein-filling in place.

(8) The quartz in the veins is identical in microscopic characters with that of the granodiorite intrusives in the vicinity. The quartz of the white quartz bodies and cross-veins is closely similar to that of the quartz-rich pegmatitic veinlets of the district.

(9) The hydrothermal alteration present in the veins and adjacent hornfels, is analogous to that which characterises the plutonic rocks of the district, and their adjacent hornfels.

To summarise, the Walker veins possess many of
the characteristics of the igneous rocks in the district; that they consist chiefly of quartz, and contain notable amounts of sulphides, can be no bar to the view that they are indeed igneous intrusives. On the other hand, the simplest explanation is not necessarily best, and it is possible that these ores were formed by metasomatic replacement of a schist in such a manner as to leave no indications of the process.

Contact Metamorphic Ores.

The deposits of the Lena and Highland Boy mines are due to the alteration of the sediments by emanations from the adjacent intrusive. This type of alteration is usually ascribed to metasomatic replacement of the original rocks by dilute solutions able to penetrate sub-microscopic fissures in the rocks; the interstitial shape of the sulphide grains is usually held to be due to replacement of interstitial calcite and other minerals by sulphides (Mineral Deposits, p.704); and the textures in the sulphides are usually referred to successive sulphide replacements. The observations made on the features of the Highland Boy and Lena deposits afford little evidence in favor of these views, but do not, of course, disprove them.

An alternative explanation may be suggested. The change of a sedimentary rock to a hornfels may not neces-
sarily be accompanied by the passage of dilute solutions, and the removal of dissolved material. If mixed substances are brought into conditions of temperature and pressure in which they are unstable, they will, in the presence of very small amounts of stationary solvents, tend to dissolve and simultaneously redeposit as more stable compounds. This process may be what is meant in part, by the "metasomatic replacement" of Lindgren and others; but it might be better described as "recrystallisation". In the Lena and Highland Boy deposits the local intrusives seem to have provided the necessary solvents by the injection of quartz veinlets (and pegmatite veinlets) carrying sulphides. These may have been viscous "ore-magnas". They were almost obliterated by the development of the garnet, epidote, and other minerals in the injected mass, and the unconsolidated sulphides assumed form as interstitial blebs in the rock. On cooling, the constituents of the sulphide solid solutions, or mixtures, "unmixed" with the formation of the intergrowths already described. Metasomatic replacement may have played some part, but the process as a whole may be described as "emplacement and recrystallisation". It is possible that dilute solutions were present only in very small amounts, and that the solution which took place was chiefly pepsitisation to viscous colloids. Chemically, the process was
marked by the formation of silicates and by the elimination of carbon dioxide, possibly as a gas.

The contact metamorphism at the Lena and Highland Boy mines is transitional into a type of alteration and mineralisation characterised by quartz veinlets, at McGill's tunnel, and in the hornfels at some distance from the intrusive contact.

Vein Deposits.

The Grizzly vein is a fissure vein, attended by hydrothermal alteration of the walls. It is not certain whether it was deposited by dilute solutions, or consolidated from a viscous inject. The interstitial character of the sulphides favors the latter view, and the graphic intergrowths of bornite in chalcocite, transitional into grains of bornite with "mutual boundaries" to chalcocite, may be due to sulphide unmixing.

The copper-bearing veinlets of the Ward Creek belt are small fissure veins, attended by hydrothermal alteration. Some of these small veins contain abundant copper sulphides. In some veinlets one or two inches wide, the sulphides and calcite occur in relatively coarse masses which alternately occupy the whole veinlet from wall to wall. This seems to support the view that they formed from a stationary unconsolidated vein-filling.
Secondary Enrichment and Oxidation.

The Mt. Ingalls district seems to have suffered continued heavy erosion since the formation of the ore-deposits; the oxidised zones are confined to a depth of fifty feet or less from the surface. The Lena, Highland Boy, McGill's Tunnel, and Ward Creek deposits show the effects of superficial oxidation, resulting in the formation of malschite. The bornite is peripherally altered to sky-blue chalcocite containing specks of covellite; this is probably due to oxidation. The occurrence of white and pale blue chalcocite in graphic intergrowths with bornite may be due to secondary enrichment, since the material examined came from near the surface. At the Lena Mine no white and pale blue chalcocite were noted, but chalcopyrite is found in beaded intergrowths in bornite. C. F. Tolman (private communication) has found such intergrowths to be confined to the superficial zone in the copper deposits of the Foothills Copper Belt, California. These chalcopyrite forms in bornite at the Lena mine may therefore be due to secondary enrichment.
Regional Relations.

The copper deposits of the Genessee belt were derived from underlying and intrusive granodioritic rock magmas by processes of differentiation. The Engels deposit, at the north end of the belt, consists of sulphides occurring in a norite segregate and accompanied by "pneumatolytic" and later hydrothermal action. The granitic dike in the Walker Mine is an acid plutonic rock formed by segregation, and contains notable amounts of copper; "pneumatolytic" action and later hydrothermal alteration are present. The plutonic intrusives outcropping in the Mt. Ingalls district and near Genessee produce small copper deposits on their contacts. It has been suggested above that the Walker veins are intrusive igneous dikes of quartz and sulphides, segregated in a large underlying reservoir. The smaller hydrothermal veins, by reason of their freedom from evidence of dynamo-metamorphism, are considered to belong to the same general epoch of ore-formation, and probably represent the expiring phases of the ore-forming processes.

Extended contemplation of the smaller ore occurrences in the Mt. Ingalls district suggests the view that they represent localised segregation and localised emplacement, without extensive or diffuse spread of ore-forming solutions. This impression favors the adoption of the theory of formation by injection of viscous segregates,
since this mode of formation requires much less room for action.
INTRODUCTION.

The Mt. Ingalls district comprises the Mt. Ingalls massif, lying between Genessee Valley and the canyons of Red Clover Creek and Little Grizzly Creek, Plumas County, California. The material presented in this report is compiled from various sources, especially from microscopic and field studies by the author. Emphasis is laid on details affecting the problems of the genesis of the ores.

GEOLOGICAL FORMATIONS.

The oldest formation in the district is the pre-Silurian metarhyolite which occurs on Little Grizzly Creek. Above this is the Taylor meta-andesite, a uralite porphyrite which is locally schistose, and the Peale formation, composed of sandstones, shales, and some cherts; these two formations belong to the Calaveras group, of Upper Carboniferous age. Above these lies the Robinson formation, composed of sandstones and shales, with a few limestone lenses and conglomerate beds. The Kettle meta-andesite, a series of sericitised flow rocks with some shale horizons, lies disconformably on
the Robinson formation. These formations are of Upper Carboniferous age. The Nix porphyrite, an andesitic rock of obscure relations which occurs near the Highland Boy mine, is provisionally assigned to the uppermost Carboniferous.

The Trail formation, of Lower Jurassic age, lies unconformably above the Carboniferous beds. It is composed of igneous detritus deposited under continental conditions. The altered rocks in which the Walker veins occur are provisionally assigned to this formation, on the basis of their lithology and structural position.

The Hull meta-andesite, a series of altered flow rocks of Lower Jurassic age, occurs on the western side of the district. Near McGill's Tunnel occurs an altered trachytic flow rock, which is described as the McGill porphyrite; it is provisionally assigned to the Lower Jurassic. Remnants of auriferous gravels, of Neocene age, occur in the district, and the broader valleys are filled with Quaternary alluvium.

The district is underlain by a part of the Sierra Nevada batholith; on the surface occur exposures of granodiorite and quartz diorite, some of which appear to be separate intrusive plugs, while others may be apophyses of an underlying mass. These rocks are of late Jurassic or early Cretaceous age. Near Curtner's
gravel mine occurs a dike of dense quartz diorite porphyry, which is probably of early Tertiary age. The pre-Tertiary rocks are overlain in part by remnants of black basalt sheets, and by a thick series of gray basalt flows, which form the cap of Mt. Ingalls. These basalts are of Tertiary age, and are older than some of the auriferous gravels. There occur exposures of a volcanic agglomerate which is younger than the auriferous gravels.

**Structural Geology.**

The pre-Tertiary structure consists of an overturned monocline of Carboniferous beds, striking roughly north and south and dipping steeply to the west; the base is against the metarhyolite on the west, and the monoclinal series are overlain unconformably by the Jurassic sediments on the east. This structure is intruded and disturbed by the granodiorite and quartz diorite rocks. The Tertiary volcanic rocks and gravels lie unconformably on this pre-Tertiary basement.

**Physiography.**

The late Cretaceous structure was uplifted and eroded to a mature surface during the Tertiary. Across this surface a drainage system ran northward, depositing a series of gravel beds; during this time the region was at no great elevation above sea level. During the Tertiary sheets of lava, chiefly basaltic,
were poured out over the surface, and were partly eroded before the close of the Tertiary. The old mature surface was then uplifted and deeply dissected by streams draining into the Sacramento Valley. The bench gravels now lie at an elevation of 5800-6200 ft. The maximum relief in the Mt. Ingalls district is over 4000 ft. During the glacial epoch there was some local glaciation, but the effects were insignificant.

Ore-Deposits.

The Tertiary bench gravels contain some gold, but the difficulty of obtaining sluicing water, and of impounding debris, has put an end to attempts to mine them. The gold content is partly concentrated in the beds of the present streams, but these deposits are now worked out, except for the stretch of gravel at Curtner's mine.

The bedrock deposits are of several types. A number of quartz veins are found, which have suffered dynamo-metamorphism; these are described as the "older quartz veins"; they antecede the latest granodiorite intrusives. Numerous hydrothermal fissure veinlets, carrying copper sulphides in a gangue of unsheared quartz and calcite occur on Ward Creek. At the Gruss mine these occur together with several veins of the older type. This mine produced high-grade gold ore; the gold is
thought to have been contained in the older veins. At the Grizzly prospect, on Little Grizzly Creek, there occurs a hydrothermal fissure vein of massive quartz, carrying bornite and chalcocite, in the Taylor meta-andesite.

The Lena mine ore-body is a dissemination of bornite, chalcopyrite, and sky-blue chalcocite in recrystallised sediments; the Highland Boy mine is similar, but white and pale blue chalcocite are present, and some of the ore occurs in the adjoining porphyrite. At McGill's tunnel there occur local impregnations of sulphides in the porphyrite and hornfels. These are contact metamorphic deposits, genetically connected with the nearby granodiorite intrusions.

The Walker ore-bodies are veins of high-temperature type occurring in the sediments, of probable Jurassic age, south of Rocky Point. The country-rock near the veins is an entirely recrystallised hornfels composed of quartz, calcic plagioclase, enstatite, biotite, and garnet, with occasional cyanite; small amounts of tourmaline are typically present. Near the veins the character of the hornfels is approximately uniform. On the surface, to the west of the veins, and in the hanging-wall east of the veins (as shown in a flat cross-cut diamond-drill hole from the south end of the mine) the hornfels gives place in a few hundred feet to in-
completely recrystallised feldspathic sediments. To the north of the veins the surface exposures contain much tourmaline and damourite mica, and hydrothermal alteration is strong.

The veins are of massive medium-grained quartz carrying sulphides. They are of irregular lenticular shape, and in most sections contain tabular horses of hornfels; they are attended by parallel smaller stringer veins on the hanging and foot-walls. The strike is a few degrees west of north and the dip 50-70°E. There are three principal sections; the central ore-body (Plate II) which is terminated on the north by a fault, and on the south by a granitic dike; the north ore-body, lying north of the fault (Plate IV); and the south ore-bodies, south of the granitic dike (Plates I and V).

The vein-filling consists of massive medium grained quartz, containing aggregates of sulphides and magnetite in interstitial forms associated with varying amounts of biotite, chlorite, actinolite, quartz, epidote, and calcite. The biotite appears to be later than the main vein quartz and to have crystallised before the sulphides. The chlorite, actinolite, epidote, and calcite are secondary, in part after biotite, and penetrate the vein quartz. These minerals are described as "second generation gangue". The proportion of this gangue
in the interstitial aggregates varies.

The contact of the vein-quartz with the hornfels is sharp and of grain-to-grain interlocking type. There is often a development of coarser grain and more abundant garnet in the hornfels adjacent to vein-quartz. The hornfels is traversed by numerous microscopic quartz veinlets which are frozen on the walls. The hornfels is impregnated with sulphides, which are most abundant near vein quartz and which diminish away from the veins. Sections of the rock near the veins assay from 0.10-0.35% copper. In places there are quartz-garnet-chlorite streaks on the quartz-hornfels contacts; the chlorite is secondary after biotite. In the north and south ore-bodies the quartz vein grades into the hornfels by a transitional "dark quartz" phase, which is composed of small irregular blocks of highly-silicified country-rock surrounded and penetrated by vein-quartz.

The grade of the ore is influenced by the amount of included matter in the veins. It is highest in the widest portions, which are at the same time relatively free from included matter. The massive ores consist chiefly of pyrrhotite, chalcopyrite, and cubanite; the cubanite occurs as oriented blades in the chalcopyrite; minor amounts of sphalerite, magnetite, and pyrite occur. Rarer constituents are galena,regnolite(?), lüllingite,
tetrahedrite, stibnite, and gold. These rarer constituents are concentrated in places in the richest parts of the central ore-body. They may occur throughout the ores in minute grains. These rarer constituents show a variety of intergrowth structures. Pyrite occurs in peculiar spheroidal forms, containing central voids into which project crystal-encrusted ribs of dense pyrite; the central voids are continuous with apertures in the shell. Cavities in the enclosing chalcopyrite preserve the spheroidal form opposite the apertures.

The ore-bodies contain cross-veins of coarser quartz which are in part connected with coarse quartz bodies in the main vein filling. Some of these cross-veins are of hydrothermal fissure vein type. There occur also barite patches in the veins, and barite cross-veinlets occur. No external origin could be found for these occurrences; they are thought to be genetically connected with the main veins.

Several igneous rocks occur in the Walker mine workings. The "adit granodiorite" cuts off the veins on the south. It is a quartz diorite containing a little microcline. The "granitic dike" intersects and offsets the vein (Plate I). It is a peculiar rock, containing about 50% quartz, 30% zoned plagioclase feld-
spar, 10% microcline, 5% biotite, some tourmaline and colorless mica, and no hornblende. The texture of the adit granodiorite and granitic dike are described and figured. The sequence of crystallisation is (1) plagioclase phenocrysts; (2) hornblende, coarse biotite, coarse quartz and microcline; (3) concentration residuum of dense biotite, quartz, and microcline. The granitic dike locally contains a little copper. A pegmatite veinlet, originating in it carries chalcopyrite associated with chlorite and damourite. These rocks are both later than the Walker veins. They have produced little alteration in the adjoining rocks.

The veins and country rock have suffered some hydrothermal alteration. In the veins, where biotite is scanty it is completely altered to chlorite; where it is abundant the alteration is only partial. In the hornfels the biotite is uniformly slightly altered.

The outcrops of the Walker veins are completely oxidised to a depth of 50 feet or less; below this there is a zone stained with chalcocanthite, in which some alteration of sulphides to sooty chalcocite occurs. The effects of oxidation are negligible 200 feet below the surface, except along faults, near which are found spangles of native copper down to the 7th level.
Microscopic characters of the Quartz.

The microscopic characters of the quartz of the igneous rocks, schistose sediments, older quartz veins, Walker veins, hydrothermal fissure veins, of the rocks contact-metamorphosed by the granitic intrusives, and of the Walker hornfels, are described. It is concluded that the quartz of the Walker veins and cross-veins is similar to that of the granodiorites and their pegmatites, respectively; that the quartz of the Walker hornfels is similar to that of the contact-metamorphosed rocks; and that the Walker veins and hornfels have suffered little dynamo-metamorphism since their formation.

Genesis of the Ores.

The principal hypotheses of ore-deposition are briefly considered, and some comments are made on the injection theory. A hypothesis of the origin of the Walker ores, based on the injection theory, is presented; the possibility of origin by replacement is however recognized. The usual view of the origin of the contact metamorphic ores is stated, and an alternative view is suggested. The relations of the copper deposits of the Mt. Ingalls district and Genessee belt, including the Engels and Superior mines, are considered, and it is suggested that the copper deposits were formed by several types of segregation in a cupriferous granodioritic magma reservoir.
BIBLIOGRAPHY


SKETCH MAP
OF
GRANITIC DIKE EXPOSURES
NEAR ADIT INTERSECTION
WALKER MINE
from data of P. Billingsley, T. Lyon, and C. de Arrieta
by permission of
WALKER MINING CO.

LEGEND
Vein Matter
Granitic dike
Faults
Country rock is hornfels

FIFTH LEVEL
Elev. 6445
SEVENTH LEVEL
Elev. 6203
SIXTH LEVEL
Elev. 6332
INTERMEDIATE LEVEL
Elev. 6580

SCALE OF FEET
Datum is Mean Sea Level

Drawn by J. C. Ewing
December 1926
LEGEND
Sections are on vertical planes bearing 38°50'W. Vertical lines are traces of a vertical reference plane which bears 38°50'W.
Black areas indicate stopes and pillars.
Dashed lines indicate veins exposed in development openings.

CROSS-SECTIONS AT 50-FT. INTERVALS
OF A PART OF THE
MAIN OREBODY
WALKER MINE

From data of C.de Arrieta, Chief Engineer
by permission of
WALKER MINING CO.

Drawn by D.C. Femy
December 1926
GENERALISED LEVEL PLANS
OF THE
NORTH OREBODY
WALKER MINE

From data of R.Billingeley, T.Lyon, and C.de Arrieta
by permission of
WALKER MINING CO.

PLATE IV
GEOLOGICAL PLAN
OF
SOUTH END OF ADIT LEVEL
WALKER MINE

from data of
P. Billingsley, T. Lyons, & C. de Arrieta:
by permission of
WALKER MINING CO.
NOVEMBER 1986
Fig. 1 - Looking north from Walker Mine Upper Camp. The outcrop crosses the skyline in the center of the picture. The holes are caved to the second level.

Fig. 2 - Collar of old shaft Upper Camp.

Fig. 3 - Stope in fault drag, Gruss Mine.
Fig. 1 - Veinlets in shale, Gruss Mine.

Fig. 2 - Veinlets in contact hornfels, ridge above Lena Mine.

Fig. 3 - Agglomerate, near Lovejoys.
Fig. 1 - Genessee from Rocky Point, in winter.

Fig. 2 - Piute vein outcrops, looking north.
Figure 1 - Basic secretion phase of granodiorite near Lena mine, showing normal texture of biotite and hornblende. h-hornblende, b-biotite.

Figure 2 - Dendritic magnetite in aggregate of hornblende grains, probably a late magmatic alteration of original augite. Granodiorite from ridge east of Grizzly claim. black, magnetite; h-hornblende.

Figure 3 - The same rock as in Figure 2. Photograph shows an augite grain, with border of hornblende or biotite, altered to brushy uralite with secondary magnetite by late magmatic reaction. The border is now chlorite.

Figure 4 - Grain of quartz in granodiorite, near Lena mine. Near extinction position, showing anomalous extinction.
PLATE IX

**Fig. 1**
x15, one nicol

**Fig. 2**
x40, one nicol

**Fig. 3**
x35, one nicol

**Fig. 4**
x35, crossed nicols
Figure 1 - Granitic dike, Walker Mine; showing three generations of minerals. Zoned plagioclase (p), first generation; coarse quartz (q) and microcline (m), second generation; the dense aggregates of biotite and other minerals form the third generation, or "concentration residuum".

Figure 2 - Same, between crossed nicols.

Figure 3 - Aplitic intergrowths, fine-grained quartz, and biotite, forming an interstitial complex, or "concentration residuum", between earlier formed grains of quartz and feldspar. Granitic dike, Walker Mine.

Figure 4 - Same as Fig. 3, but between crossed nicols.
Figure 1 - Fine-grained biotite, of the interstitial complex or "concentration residuum", replacing a first-formed grain of plagioclase feldspar. Granitic dike, adit level, Walker Mine.

Figure 2 - Same, between crossed nicols.

Figure 3 - Tourmaline replacing a microcline grain, granitic dike, Walker Mine. tm, tourmaline; m, microcline.

Figure 4 - A complex grain of microcline and plagioclase, with some graphically intergrown quartz, being replaced by a damourite aggregate. Pegmatite area in granitic dike, Walker Mine.
PLATE XI

Fig. 1
x65, one nicol

Fig. 2
x65, crossed nicols

Fig. 3
x27, one nicol

Fig. 4
x15, crossed nicols
Figure 1 - Typical vein-quartz with sulphide-silicate grains, Walker Mine.

Figure 2 - Same between crossed nicols.

Figure 3 - Dense pyritic aggregate, with chlorite, in irregular quartz stringer cutting hornfels, south end, Walker Mine.

Figure 4 - Chalcopyrite in chlorite-damourite-calcite aggregate in pegmatite stringer; granitic dike, adit level, Walker Mine.
PLATE XII

Fig. 1
x25, one nicol

Fig. 2
x25, crossed nicols

Fig. 3
x15, one nicol

Fig. 4
x70, one nicol
Figure 1 - Bornite intergrown in chalcocite, Highland Boy Mine. White, bornite; light gray, chalcocite; dark gray, gangue. This is a grain in contact metamorphic rock. Note the smooth subhedral form of the gangue grains in the sulphides.

Figure 2 - A grain of bornite (light gray) with lattice of chalcopyrite blades (white) altering to blue chalcocite (gray). The chalcocite is etched. It is attacking the grain on the outside and penetrating along the sides of the chalcopyrite blades. A grain in contact metamorphic rock, Lena Mine.

Figure 3 - Grains of bornite and chalcopyrite (white), Lena Mine. The irregular outline of the grains corresponds to the irregular grain of the garnet, epidote, clinzoisite, etc. which form the rock.

Figure 4 - A grain of bornite (light gray) with lattice of chalcopyrite blades (white), Lena Mine. Note the smooth-outlined spot of chalcopyrite, and the irregular alteration to blue chalcocite (gray).
Fig. 1
x170, etched with KCN

Fig. 2
x200, etched with KCN

Fig. 3
x25, unetched

Fig. 4
x130, unetched
Figure 1 - Intergrowth of bornite (gray) in blue and white chalcocite (white), Grizzly vein. The veinlet is of malachite bordered by patches of blue chalcocite rich in covellite.

Figure 2 - Bornite (white) intergrown in chalcocite (etched gray), Grizzly vein. The etching shows that the chalcocite in the intergrowth is all one crystal.

Figure 3 - Bladed intergrowth of white and blue chalcocite, Grizzly vein. The right of the figure is unetched. The apparent twinning is due chiefly to the bladed intergrowth.

Figure 4 - Patterns of white chalcocite in blue, Highland Boy prospect. Brought out by light etching, and red filter.
Fig. 1
x75, unetched

Fig. 2
x125, etched with KCN

Fig. 3
x65, etched with KCN

Fig. 4
x400, etched with KCN
Figure 1 - Quartz grains in sulphides and magnetite, Walker Mine. The specimen is chiefly pyrrhotite (white). The quartz grains (black) have fairly smooth outlines, and contain numerous rounded shapes of the ore minerals.

Figure 2 - A specimen in which the sulphides and gangue are present in equal amounts; south end, Walker Mine. The photograph shows a grain of magnetite (gray) containing smooth forms of pyrrhotite (white); light gray, chalcopyrite; black, quartz. The subhedral character of the quartz is shown, also the smooth boundaries of the sulphides and magnetite to each other.

Figure 3 - A grain of sulphides (white) in vein quartz (gray), Walker Mine, showing the interstitial shape towards the main quartz, and the irregular second-generation gangue (chlorite, biotite, quartz, etc.) contemporary with the sulphides.

Figure 4 - Another grain of sulphides (white) in quartz (dark gray), Walker Mine, showing contrast between the vein-quartz and the second generation gangue in the sulphides.
Figure 1 - Pyrrhotite (white), chalcopyrite (light gray), sphalerite (darker gray) with second generation gangue (very dark gray), Walker Mine. Shows complex boundaries of the gangue, and the mutual boundaries of the sulphides.

Figure 2 - Typical massive sulphides, Walker Mine, chiefly chalcopyrite (gray ground) containing oriented blades of cubanite (light gray) and irregular islands of pyrrhotite (light gray, high relief). Black is quartz; the subhedral shape is shown.

Figure 3 - Massive sulphides, Walker Mine. The light gray blades are cubanite, the gray field is chalcopyrite; black, quartz. The small irregular white grains with high relief are pyrite.

Figure 4 - A small pyrite grain in pyrrhotite, Walker Mine. The grain shows the rounded form and concentric structure suggesting colloidal origin.
Fig. 1
x170, unetched

Fig. 2
x10, unetched

Fig. 3
x15, unetched

Fig. 4
x25
Figure 1 - A small pyritic spheroid with central quartz (dark gray) in chalcopyrite (light gray). The pyrite is white. The dendritic ribs of pyrite are seen, and the open spaces (black) which form an essential part of the spheroids. Walker Mine.

Figure 2 - A rib of a pyritic spheroid (white) in chalcopyrite (light gray). Dark gray, open space (filled with Canada balsam). The pyrite crystals which encrust the ribs of the spheroid are seen in cross-section. Walker Mine.

Figure 3 - A pyritic mass (white) showing open space (black) and inclusions of chalcopyrite (smooth light gray) and sphalerite (smooth dark gray). Walker Mine.

Figure 4 - A grain of sphalerite (gray) in chalcopyrite (white) Walker Mine, showing symmetrical inclusions of chalcopyrite in sphalerite.
PLATE XVIII

Figure 1 - A grain of magnetite in pyrrhotite, Walker Mine. The light colored inclusions in the magnetite (dark gray) are probably hematite. The smooth outline of the grain is shown.

Figure 2 - Intergrowths of löllingite (white) in chalcopyrite (light gray), Walker Mine. Note the sharp outlines of the intergrowth areas, and the tendency to cluster on the gangue (dark gray). The contrast between the main quartz and the second generation gangue may also be seen.

Figure 3 - Löllingite - chalcopyrite intergrowths (flecked) in chalcopyrite (light gray), associated with second generation gangue and vein quartz. Walker Mine.

Figure 4 - Löllingite (white) intergrown with chalcopyrite (gray) forming a grain in quartz. Note that the clustering of the löllingite on the gangue has cleared the surrounding chalcopyrite. Walker Mine.
Figure 1 - Intergrowth of löllingite (white) with chalcopyrite (light gray) and a mineral which is probably sphalerite (dark gray). Walker Mine.

Figure 2 - Intergrowth of löllingite (white) with chalcopyrite (gray field) and a soft grayish white mineral (light gray, low relief). Note the variation in the size of grain. The large black spots are quartz grains, the small spots are pits in the specimen.

Figure 3 - Massive galena (white) and chalcopyrite (gray). The lighter gray mineral is tetrahedrite; the white flecked areas are löllingite-chalcopyrite intergrowths. The sharp outlines of the intergrowths are shown.

Figure 4 - Massive galena (white) containing partly intergrown tetrahedrite (light gray) garnet (g) and quartz (q). Shows the euhedral form of garnet and subhedral form of quartz embedded in sulphides.
PLATE XIX

Fig. 1
xl40, unetched

Fig. 2
x85

Fig. 3
xl0

Fig. 4
xl2
Figure 1 - Intergrowth of galena (black) with regnolite(?) (light gray). The white mineral is stibnite. The percentage of the constituents appears to be constant and independent of the coarseness of the grain. Walker Mine.

Figure 2 - Intergrowth of galena (dark gray) with regnolite(?) (light gray), with associated stibnite (white, low relief) and a few grains of lollingite (white, high relief). Shows the crystals form of the stibnite. This section is a cross-section of a columnar structure; the stibnite is actually in needles.

Figure 3 - Same intergrowth as Figures 1 and 2 but with no stibnite or lollingite. Shows the sharp grain boundaries and difference in coarseness of texture.

Figure 4 - Same intergrowth as in Figure 1; the complex appears to be made up of different areas, within which the orientation is roughly parallel.
Fig. 2
x250, etched with HCL

Fig. 4
x32, etched with HCL
Figure 1 - The border of a grain of tetrahedrite (t) and regnolite (?) (r) with intergrown galena (dark), Walker Mine. Shows the "beach" of minute löllingite grains (white, high relief). The specks are fewer where larger crystals have developed. Some stibnite (white with low relief) is present in the regnolite (?) but not in the tetrahedrite.

Figure 2 - Oriented inclusions of löllingite in tetrahedrite (gray field), Walker Mine.

Figure 3 - Inclusions of galena (black) and löllingite (high relief) in tetrahedrite (gray field), Walker Mine.

Figure 4 - Intergrowth of löllingite (white) with chalcopyrite (gray, high relief) in galena (etched ground) Walker Mine. Part of a small grain in other parts of which the constituents are free from admixture.
Fig. 1
x200, etched with HCL

Fig. 2
x450, unetched

Fig. 3
x385, etched with HCL

Fig. 4
x210, etched with HCL
PLATE XXII.

Figure 1 - Grains of intergrown sulphides in quartz vein (dark gray), Walker Mine. Shows the usual interstitial character of the grains. Some second generation gangue can be seen. A shear-crack, filled with sulphides, and connecting two grains, may be seen.

Figure 2 - More complex grains of sulphides in quartz, Walker Mine. The quartz grains have smooth undulating or subhedral shape, under higher magnification. There is some evidence of shearing, before the sulphides consolidated.

Figure 3 - A simple grain of sulphides in quartz composed of a fairly uniform intergrowth of galena (gray) and regnolite (?) (white). The white grain with high relief is lüllingite.

Figure 4 - A more complex grain, composed of galena (etched gray), regnolite (?) (light gray), and lüllingite (white).
PLATE XXII

Fig. 1
x25, etched with HCL

Fig. 2
x12, unetched

Fig. 3
x55, etched with HCL

Fig. 4
x67, etched with HCL
Figure 1 - Grains of intergrown löllingite (white) chalcopyrite (light gray, high relief), and galena (low relief) in quartz (q) and garnet (g). Walker Mine.

Figure 2 - A complex intergrown-sulphide grain in quartz, Walker Mine. The white flecked areas are intergrowths of löllingite and chalcopyrite; this phase is in turn intergrown with galena (etched ground). The smooth gray sulphide areas are tetrahedrite and chalcopyrite free from löllingite.

Figure 3 - A grain similar to that in fig. 2, but showing variation in grain in the löllingite-chalcopyrite intergrowths.

Figure 4 - Detail of complex connecting sulphide grains; showing evidence of movement. White, regnolite(?); white with high relief, löllingite; black, galena (etched). Shows also the penetration of quartz by löllingite crystals.
PLATE XXIII

Fig. 1
x20, unetched

Fig. 2
x180, etched with HCL

Fig. 3
x30, etched with HCL

Fig. 4
x30, etched with HCL