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GEOLOGY OF THE HUMBOLDT REGION AND THE IRON KING MINE, BIGBUG MINING DISTRICT, YAVAPAI COUNTY, ARIZONA

by

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REPORT ON HUMBOLDT REGION, AND IRON KING MINE, YAVAPAI COUNTY, ARIZONA, RELEASED

A preliminary report on the Humboldt region and the Iron King mine, Yavapai County, Ariz., has been placed on open file for public inspection, the Geological Survey, U. S. Department of the Interior, announced today.

The Iron King mine and the Humboldt region are 12 airline miles east of Prescott, Ariz. Metamorphosed pre-Cambrian volcanic rocks that have been intruded by granitic rocks ranging in composition from granites to gabbro form the bedrock. Cenozoic river wash and valley fill, including some interbedded basalt, locally mantle the pre-Cambrian rocks. At the Iron King mine, ores of lead, zinc, gold, and silver are extracted. Twelve steeply plunging echelon veins occur along the foot-wall of a sheared and altered zone in meta-andesite tuff. The veins are the "massive sulfide" type and contain quartz, ankerite, pyrite, arsenopyrite, sphalerite, galena, chalcopyrite, and tennantite.

The report, titled "Geology of the Humboldt region and the Iron King mine, Bigbug mining district, Yavapai County, Arizona," by S. C. Creasey, is accompanied by a geologic map of the Humboldt region, mine maps, cross sections, and other illustrations. Copies of the report and maps may be examined at the U. S. Geological Survey, Room 1033 (Library), General Services Building, Washington, D. C.; Arizona Bureau of Mines, Tucson, Ariz.; and the Library, University of California, Los Angeles, Calif.

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CONTENTS

CONTENTS (continued)

ILLUSTRATIONS

GEOLOGY OF THE HUMBOLDT REGION AND THE IRON KING MINE, BIGBUG MINING DISTRICT, YAVAPAI COUNTY, ARIZONA.

S. Cyrus Creasey

ABSTRACT

The Humboldt region is in central Yavapai County, Arizona. The intersection of the 112° 15' meridian and the 34° 30' N. parallel is in the approximate geographical center of the region, and the Iron King mine is about 2000 feet west-northwest of the intersection.

Pre-Cambrian rocks form the bedrock in the Humboldt region. Late Cenozoic unconsolidated river wash and valley fill, including some interbedded basalt, locally mantle the pre-Cambrian rocks, especially in the north-central part of the region (Lonesome Valley).

The pre-Cambrian rocks consist of five newly defined metavolcanic formations derived from flows and tuffs, and of six intrusive units ranging in composition from granite to gabbro or perhaps more mafic types. Relic bedding and pillow structures are locally prominent in the metavolcanics; geopetal structures are uncommon, but where present, generally indicate that the top is toward the west, though the evidence is too meager to be conclusive.

Low-grade dynamothermal metamorphism altered the metavolcanics and to a lesser extent the intrusive rocks, forming textures, structures, and mineral assemblages characteristic of low temperature and moderate stress.

The Texas Gulch formation, which is the easternmost metavolcanic formation, consists of five lithologic units. Arranged in the general order of their appearance from east to west they are meta-andesite breccia, purple slate, metarhyolite tuff, meta-andesite, and green slate. The boundary between the Texas Gulch formation and the Iron King meta-andesite is apparently gradational.

The Iron King meta-andesite consists of three meta-andesite tuff units, two meta-andesite flow units and one metarhyolite tuff and conglomerate unit. The assemblage chlorite-albite-epidote with or without quartz is dominant in the meta-andesites. Mafic intrusive rocks, which may be approximately contemporaneous with metamorphism, may explain the presence of actinolitic hornblende in the central part of the formation.

Toward the west the Iron King meta-andesite appears to grade into the Spud Mountain metabreccia through a zone containing beds characteristic of either one formation or the other. The Spud Mountain metabreccia consists of interbedded metabreccia and metatuff beds. The metatuffs are largely andesitic in composition, but a few thin beds of metarhyolite tuff occur. The fragments in the metabreccia beds consist chiefly of porphyritic meta-andesites and the matrix is meta-andesite tuff.

Pre-Cambrian faults now marked by dikes separate the Chaparral Gulch metavolcanics, which lie west of the Spud Mountain metabreccia, from underlying and overlying formations. The Chaparral Gulch metavolcanics contain metarhyolite tuff, metarhyolite flow, and meta-andesite tuff that locally was contaminated by rhyolitic detritus.

The Indian Hills metavolcanics, which are northeast of the Chaparral Gulch metavolcanics, consist of two broad units, one composed of metarhyolites and the other of meta-andesites. Metamorphosed tuffs and flows are believed to be represented in both units and flow breccia in the meta-andesites.

Granite and alaskite; granodiorite and quartz diorite; diorite, mafic quartz diorite, gabbro and diabase; metarhyolite (?); and quartz porphyry comprise the pre-Cambrian intrusive units mapped. They include both deep-seated and hypabyssal types. Dynamothermal metamorphism has foliated the smaller bodies and the margins of the larger masses and partly converted them into mineral assemblages stable under low-grade metamorphic conditions.

Planar structures (chiefly foliation) are omnipresent and linear structures are common in the pre-Cambrian meta-volcanic rocks. North-trending planar structures dominate in the Indian Hills metavolcanics, and in the Spud Mountain metabreccia, whereas northeast-trending planar structures are dominant in the Texas Gulch formation, Iron King meta-andesite, and Chaparral Gulch metavolcanics. To a lesser extent northeast-trending structures that are younger than those trending northward occur also in the Spud Mountain metabreccia. Lineation, plunging steeply northward is common in the Iron King meta-andesite and is present locally in the northern outcrops of the Texas Gulch formation. It commonly plunges steeply southward in the southern part of the Texas Gulch formation.

Three steeply plunging folds are limited to the outcrop area of the Texas Gulch formation, and the outcrop pattern of the purple slate and metarhyolite tuff units suggests others, though lenticularity may cause the abrupt termination of outcrops in some places. Many folds of magnitude similar to those known and believed to exist in the Texas Gulch formation could be masked by the uniform lithology in the Iron King meta-andesite, Spud Mountain metabreccia, and the Indian Hills metavolcanics. One nearly isoclinal anticline was recognized in the Chaparral Gulch metavolcanics.

Although no folds of a magnitude that would duplicate formations, can be proved, the possibility of at least one such fold is suggested by the similarity of the lithology between the metarhyolite tuff and conglomerate unit in the Iron King meta-andesite and the metarhyolite tuff unit in the Texas Gulch formation. On the basis of this assumption, the Spud Mountain metabreccia and the western metatuff unit in the Iron King meta-andesite would be correlative to the meta-andesite breccia unit in the Texas Gulch formation, and the fold axis would be in the central part of the Iron King meta-andesite.

Few faults were recognized in the Humboldt region. The metamorphosed dikes that bound the Chaparral Gulch metavolcanics mark pre-Cambrian faults. The Lonesome Valley fault, which moved late Cenozoic valley fill against pre-Cambrian rocks, is the only fault that is known to have post-Cambrian movement. Other faults of uncertain age occur in the Humboldt region.

Two zones of hydrothermal alteration not related to the Iron King mine occur. In the Iron King meta-andesite, a zone, possibly originally rhyolitic, contains introduced quartz, pyrite, and possibly sericite. Adjacent to the intrusive rocks along the eastern edge of the Humboldt region, the metarhyolite (?) contains introduced pyrite, and the metarhyolite (?), meta-andesite breccia (Texas Gulch formation), and quartz porphyry contain features suggestive of albitization.

The Iron King mine is the only active mine in the Humboldt region. It consists of twelve veins, en echelon, steeply plunging, and arranged along the footwall of a sheared and altered zone in the western meta-andesite tuff unit of the Iron King meta-andesite. Narrow zones of especially intense shear probably localized the veins.

Solutions introduced quartz, pyrite, ankerite, and probably sericite early in the hydrothermal epoch, forming a sporadically mineralized zone in the hanging wall of the deposit and probably veins in the fracture system of the Iron King mine. Subsequent shearing strongly brecciated these early minerals and formed the structures that controlled the location and distribution of the ore minerals in the veins. Following this deformation, sphalerite, galena, chalcopyrite, tennantite, arsenopyrite, pyrite, quartz, and ankerite were deposited, though the last three minerals may represent solution and redeposition of earlier minerals. Sericite either accompanied or followed the ore-forming minerals.

Silver is related closely in distribution to copper and probably is in the tennantite. Gold occurs chiefly in the pyrite.

Banding, mimetic after planar structures, is pronounced in much of the vein filling. Mineral zoning, generally similar in each vein, is characteristic of the deposit.

High-angle reverse faults of 100-foot maximum vertical displacement have offset the veins.

INTRODUCTION

The Humboldt region*, in the Bigbug mining district, Yavapai County, Arizona, comprises a rectangular area extending roughly $3\frac{1}{2}$ miles in a northerly direction and 7 miles in an easterly direction. The intersection of meridian 112° 15' and parallel 34° 30' lies close to the geographical center of the region, and the Iron King mine is about 2000 feet west-northwest of the intersection.

The towns in the area are Humboldt and Dewey. State Highway 69 (Black Canyon Highway), a secondary road between Prescott and Phoenix, Arizona, runs through the central part of the region. A graveled road connects the Iron King mine with the highway less than a mile southwest of Humboldt; dirt roads furnish access to other parts of the region. A spur line of the Atchison Topeka and Santa Fe railroad connects Humboldt with the main line at Ashfork, Arizona.

The Humboldt region is in the "Mountain region" of Arizona, as defined by Ransome (1903, p. 15). The Mountain region is characterized by nearly parallel short ranges that are separated by valleys commonly deeply filled with fluviatile and lacustrine deposits. The Humboldt region bounds the south end of Lonesome Valley, which widens northwestward and coalesces with Chino Valley.

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* "Humboldt region" refers to the area covered by Plate 1.

The region is between northeastern slopes of the Bradshaw Mountains and the southwestern foothills of the Black Hills, and forms a bedrock bridge linking the two mountain ranges. The altitude in the Humboldt region varies from 4300 feet at the point where the Agua Fria River crosses the southern boundary of the region to 5600 feet in the northeastern corner. The slopes are gentle in the central and western parts of the region and moderate in the area east of Lonesome Valley.

The region drains to the Agua Fria River which wanders across Lonesome Valley in a canyon perhaps 30 feet below the general level of the valley floor. As the river leaves the alluvium and flows on bedrock south of Lonesome Valley, the canyon walls increase greatly in height. For many miles to the southeast, the Agua Fria runs in a steep-walled slot cut in the pre-Cambrian rocks. As pointed out by Lindgren (1926, p. 8), these features suggest that the Agua Fria has captured the drainage of Lonesome Valley. All the tributary streams in the Humboldt region are ephemeral and drain into the Agua Fria River, which is perennial only where it flows on bedrock south of Lonesome Valley.

Water for the town of Humboldt, the Iron King mine, and for domestic use and irrigation by ranchers living in the region comes from wells in the alluvial fill of Lonesome Valley. Apparently gravel beds in the alluvium supply the bulk of the water.

The topography of the part of the Humboldt region south of parallel 34o 30' is shown on the Bradshaw quadrangle, 1903, on a scale of 1 to 125,000, and that north of the parallel by the Jerome quadrangle, 1905, on the same scale. The Jerome quadrangle has been remapped on a scale of 1 to 62500. The Mingus Mountain quadrangle, which covers the same area as the southeast quarter of the Jerome quadrangle, was published in 1947. The northern part of the Bradshaw Mountains quadrangle has been remapped, but the maps have not been published.

Previous work

The earliest recorded geologic work in the district was done in 1899 and 1901 by Jaggar and Palache (1905) who mapped the Bradshaw quadrangle. Their work was reconnaissance. They divided the pre-Cambrian into Yavapai schist, various coarse-grained plutonic intrusives, and one complex. The Yavapai schist, which includes most of the foliated rocks in the Humboldt region, was defined to include all of the pre-Cambrian phyllites, schists, and gneiss in local areas. Although they did not mention the Iron King mine in the text of the folio, its location was indicated on the geologic map.

In 1922 Lindgren (1926) examined the ore deposits in the Bradshaw and Jerome quadrangles, using Jaggar and Palache's geologic map of the Bradshaw quadrangle and a geologic map of the Jerome quadrangle prepared by Jenkins and Wilson of the Arizona

Bureau of Mines and by Louis E. Reber, Jr. Lindgren described the pre-Cambrian rocks, but his report deals primarily with the occurrence, history, and production of the ore deposits. The Iron King mine is described briefly. Eldred Wilson (1939) published an excellent paper on the pre-Cambrian rocks of several districts in central Arizona, one of which was the Black Hills district that borders the Humboldt region on the northeast. He distinguished three formations within the Yavapai schist, and proposed that the name Yavapai schist be replaced by Yavapai group. Wilson's paper did much to establish the chronological sequence of Arizona pre-Cambrian rocks.

Field work and acknowledgments

The field work for this report was done from October 15 to December 15, 1945, and from September 15, 1947, to April 1, 1948. This work constitutes a small part of a more comprehensive study of the geology and ore deposits in the Mingus Mountain quadrangle currently being undertaken by Charles A. Anderson and the writer for the U. S. Geological Survey.

The writer takes pleasure in acknowledging the cooperation of the staff of the Iron King Mine. H. F. Mills, General Manager, kindly permitted use of all company maps and production data on the mine, and the writer profited by many discussions with John Kellogg, Mine Geologist, on geologic problems related to the Iron King deposit. Other staff members were helpful in many ways.

The writer wishes to take this opportunity to thank (Mrs.) M. H. Krieger and (Miss) W. H. Eckstein for permission to use part of the

geologic map, which they are currently preparing for the U. S. Geological Survey, to complete the northwestern part of the geologic map of the Humboldt region (pl. 1). The writer is especially indebted to Charles A. Anderson for many stimulating discussions, visits in the field, and helpful suggestions. The advice and criticism kindly given by Drs. James Gilluly, Cordell Durrell, Joseph Murdoch, and M. N. Bramlette, faculty members of the Department of Geology, University of California, Los Angeles, are appreciated greatly.

GENERAL GEOLOGY

General features

The rocks in the Humboldt region are predominantly pre-Cambrian. Cenozoic rocks are represented by Pliocene (?) or Pleistocene (?) gravels and basalt and by Pleistocene (?) to Recent valley fill and river wash. All except the basalt are shown as alluvium on plate 1.

The pre-Cambrian of Arizona has been studied in detail only locally and complete agreement on the subdivision and age of the rocks has not been reached. Lindgren (1926, p. 15), and Wilson (1939, p. 1118), believed that the Yavapai schist in central Arizona, the Pinal schist in southern Arizona, and the Vishnu schist in the Grand Canyon area are among the earliest known pre-Cambrian rocks in Arizona. Jaggar and Palache (1905, p. 9) regarded the Vishnu and Yavapai schists as of the same age. All three of these metamorphic formations are overlain unconformably by unmetamorphosed pre-Cambrian rocks. The Grand Canyon series unconformably overlies the Vishnu schist in the Grand Canyon, and the Apache group overlies the Pinal schist in the Globe (Ransome, 1903, p. 38) and in the Ray-Miami districts (Ransome, 1919, p. 31, 39). In the Mingus Mountain quadrangle the Yavapai schist is overlain unconformably by Paleozoic sedimentary rocks, but Wilson (1939, p. 1151) shows that in the eastern Tonto Basin the Apache group unconformably overlaps the Mazatzal quartzite which in turn is believed by Wilson to lie above the Yavapai schist in the Mazatzal Mountains in central

Arizona. The Arizona State geologic map, compiled by Darton, Wilson, and Lausen, includes the Vishnu, Pinal, and Yavapai schists under Archean (?). Ransome (1919, p. 32) states that the Pinal schist in the Ray-Miami district is of possible Archean age. However, owing to the difficulties inherent in correlation between rocks in widely separated areas on the bases of lithologic and structural features, an age determination for the Yavapai schist by correlation with pre-Cambrian rocks in other terrains is believed not to be practical, and the writer prefers to use the term "older pre-Cambrian," as suggested by Wilson (1939). "Older pre-Cambrian" is not meant to imply any particular part of pre-Cambrian time; it is used to indicate that there are younger pre-Cambrian rocks in the general region.

The pre-Cambrian rocks in the Humboldt region are herein subdivided into five metamorphic formations that originated chiefly from volcanic rocks and six intrusive rock units ranging in composition from granite to gabbro or perhaps more mafic types. The metavolcanic rocks represent a small part of the Yavapai as described by Jaggar and Palache and later extended by Lindgren. With the subdivision of the metavolcanic rocks into formations, as described in this report, the Yavapai is considered a series in this area. The metavolcanic rocks are largely meta-andesite flows, tuffs and breccia; metarhyolite flows and tuffs; and metatuffs composed of mixtures of metarhyolitic and meta-andesitic detritus. Both metarhyolite and meta-andesite occur in the upper and lower parts of the sequence.

The regional strike of the formations ranges from north to northeast. Bedding dips at high angles both eastward and westward, but chiefly westward. Folds on a scale that would duplicate formations were not recognized, but several isoclinal folds were confined to the outcrop area of the Texas Gulch formation, and more may be present. One tight anticline was mapped in the Chaparral Gulch metavolcanics.

Faults of pre-Cambrian age, now marked by dikes, bound the Chaparral Gulch metavolcanics, and the fault separating the quartz porphyry and the meta-andesite breccia of the Texas Gulch formation probably is also pre-Cambrian. The Pleistocene (?) Lonesome Valley fault, which has moved late Cenozoic valley fill against pre-Cambrian rocks, bounds Lonesome Valley on the east. Other faults of uncertain age and small displacement occur in the Humboldt region. The pre-Cambrian rocks are in the chlorite zone of metamorphism as defined by Harker (1939, pp. 209-214) or the greenschist facies of Eskola (1939, pp. 357-359).

Foliation is pronounced in all the metavolcanics and in some of the intrusive rocks. North-trending foliation dominates in the Indian Hills metavolcanics and, to a lesser extent, in the Spud Mountain metabreccia. Northeast-trending foliation occurs in the rest of the pre-Cambrian rocks and locally in the Spud Mountain metabreccia. The northeast foliation in the Spud Mountain metabreccia appears to cut the north-trending, but the two structures may have been nearly contemporaneous. Linear structures plunge consistently northward at high angles in the Iron King meta-andesite and both northward and southward in the Texas Gulch formation; they are not prominent in other formations.

Pre-Cambrian metavolcanic rocks

TEXAS GULCH FORMATION

Distribution

The Texas Gulch formation, here named from the exposures in Texas Gulch, crops out in a north-trending belt in the eastern part of the area. Beds dip steeply both eastward and westward as the result of tight folding and overturning. The top of the formation is probably toward the west, as indicated by geopetal structures, though they are not numerous and widespread enough to prove this. The formation is bounded on the east by plutonic igneous rocks and on the west by alluvium of Lonesome Valley and by the Iron King meta-andesite with which it has a gradational contact. The outcrop width varies from about 3000 feet near the road to Cherry to about 6000 feet at the south edge of the map. These widths do not represent even a rough approximation of the original stratigraphic thickness, however, as the rocks are tightly folded, at least locally. The formation is exposed for about 12 miles north of the area, where it passes beneath Paleozoic sedimentary rocks and the alluvium of Lonesome Valley. The extent of the Texas Gulch formation south of the area mapped is not known.

In general the Texas Gulch formation forms the lower slopes of the Black Hills. It erodes characteristically into smooth rolling hills whose long dimensions reflect the regional strike of the foliation and of the formation. The main streams and gulches transgress the formation at high angles, and the tributaries tend to parallel the regional strike of the formation.

Petrography

The Texas Gulch formation includes five lithologic units. Arranged in order of their appearance from east to west, they are (1) meta-andesite breccia, (2) purple slate, (3) metarhyolite tuff, (4) meta-andesite, lavas and tuffs, and (5) green slate. The individual units are relatively uniform in composition except the green slate and some of the western beds of metarhyolite tuff, the mineralogic composition of which suggests that they represent gradational facies into the Iron King meta-andesite.

Meta-andesite breccia

The meta-andesite breccia occurs along the eastern edge of the Humboldt region in a band ranging from about 1000 to 4000 feet in width. It is bounded on the west by the purple slate and metarhyolite tuff and on the east by intrusive rocks. It is cut by large bodies of fine-grained metarhyolite and by small bodies of quartz porphyry. The rock is well foliated toward the north. Here it is essentially a fine-grained chlorite schist containing white streaks, probably relics of original grains of clastic feldspar or leucocratic rock fragments. The breccia fragments are visible only as ghosts in widely scattered outcrops. South of latitude 34° 30', the foliation is weaker, and the original character of the rock is much more distinct. Here bedding is commonly recognizable, and one feldspathic crystal metatuff bed 25 feet thick was traced for a mile. Geopetal structures are common, and those east of the marble bed (pl. 1) consistently show tops toward the west.

The meta-andesite breccia varies greatly in lithology in the southeastern part of the area. Near the purple slate it is fine- to medium-grained meta-andesite tuff containing abundant chlorite and saussuritized plagioclase grains. This metatuff encloses sporadic beds of purple slate (not shown on map) as much as 30 feet wide; one bed was traced more than half a mile. Marble in beds as much as 10 feet thick is abundant in a zone at least 100 feet wide in this fine-grained part of the unit. The meta-andesite tuff forms a belt 1000 feet wide along the western contact of the Texas Gulch formation in the south of the Humboldt region. The stratigraphic thickness of this tuff is not known even approximately, for it is folded into a tight syncline.

The meta-andesite tuffs grade eastward into meta-andesite breccia containing subordinate amounts of interbedded meta-andesite tuffs. The metabreccia is water deposited and individual beds probably exceed 500 feet in thickness. The fragments range from subrounded to angular and rarely exceed one foot in diameter, with an average size of pebbles in many beds of from one to two inches. The fragments are chiefly of meta-andesite, but metarhyolite (?) fragments dominate in certain beds and local areas. Commonly the matrix, even where associated with metarhyolite (?) fragments, abounds in chlorite, and hence is probably andesitic. Meta-andesite breccia predominates in the eastern part of the unit, though there are many interbeds of meta-andesite tuff and one of medium-grained feldspathic metatuff with excellent bedding and geopetal structures. Narrow exposures suggesting meta-andesite lava were seen but could not be traced far.

Chlorite, albite, epidote, and clinozoisite are the characteristic minerals of the meta-andesite breccia, and quartz, sericite, apatite, and leucoxene occur as accessories. Albite occurs as granoblastic grains and as saussuritized relics clouded with epidote minerals, sericite, chlorite, and commonly carbonate. Epidote and clinozoisite form irregular grains. Sericite occurs as microscopic flakes largely limited to saussuritized plagioclase. Quartz is granoblastic and generally constitutes only a small percentage of the rock. Some of the meta-andesite fragments display a relict porphyritic texture, consisting of plagioclase phenocrysts in a pilotaxitic groundmass.

Along the intrusive contact of the granitic rocks, the textures of the meta-andesite breccia suggest the introduction of albite. Peculiar pseudomicrographic intergrowths of quartz and albite occur and idioblastic albite crystals contain cores of saussuritized plagioclase. These alterations are discussed under the section on hydrothermal alteration not related to the Iron King ore deposit.

Purple slate

The purple slate is a fine-grained, purple to deep-maroon rock with local patches having a greenish cast. Marble beds ranging in thickness from less than one foot to as much as 15 feet are distributed erratically throughout the purple slate but are nowhere very abundant. The marble beds are quite discontinuous along the strike probably owing to local shearing of the beds. The purple slate has a very closely spaced foliation which in places is cut by pronounced cross slips or shears. No systematic pattern was recognized for these latter structures.

As can be seen on plate 1, the individual units of the purple slate vary greatly in thickness, perhaps because of differential shearing when the foliation was produced. However, it is possible that the variations in thickness are of sedimentary origin or due to folding. Perhaps all three factors have contributed.

Several bands of green slate, one of which is locally 300 feet wide, are intercalated with the purple slates in their more westerly outcrops. Lithologically the slates are identical except for color, and in a few places the purple slate grades along the strike into green for a short distance.

Metarhyolite tuff

Metarhyolite tuff is closely associated with the purple slate, and tends to sustain ridges standing above the valleys and gulches on either side carved on the purple slate. The foliation in the metarhyolite tuff is locally nearly imperceptible and elsewhere pronounced, with no obvious reason for these variations. It is generally much less perfect than that in the adjacent purple slate.

The metarhyolite tuff ranges from gray to white or cream. It is generally medium grained but commonly varies abruptly from coarse to very fine grained within a few feet across the strike. Systematic variations of this kind through several beds are rare so that the local stratigraphic sequence is generally uncertain. The metarhyolite tuff is composed predominantly of medium-grained metatuffs and of minor amounts of intercalated gray slate and metaconglomerate beds.

Quartz and sericite are the characteristic minerals. Feldspar was noted in the field, but not under the microscope. The quartz, forming up to 50 percent of the rock, is in granoblastic grains, some of which are fractured and strained. Sericite is very abundant as small flakes and patches and as "ribbons" anastomosing around the quartz grains. Small fragments of leucocratic, microcrystalline rock having an aggregate index of refraction of less than 1.540, and abundant scattered sericite flakes were interpreted as metarhyolite. Magnetite and a few grains of epidote and tourmaline (?) were recognized microscopically.

The metaconglomerate beds consist of water-worn pebbles and small boulders rarely over two inches across in a matrix identical to the metatuff described above. In some beds the pebbles are attenuated so that lengths are several times widths; in others no stretching of the pebbles was recognized. Most of the pebbles are jasper, but pebbles of a leucocratic, felsitic metarhyolite (?) are not uncommon. Some beds show few or no fragments in sections perpendicular to foliation but have lenticular streaks and patches rich in sericite on the foliation planes. The origin of these streaks and patches is uncertain, but they probably represent intensely sheared fragments of rhyolite.

Minor beds of gray slate, rarely exceeding a foot or two in width, are common. Except for color they resemble the purple slate and apparently represent metamorphosed fine-grained tuffaceous sediments.

Meta-andesite

The meta-andesite forms a lenticular mass, bounded chiefly by tuff. It is 1500 feet wide near the northern boundary of the map but wedges out southward.

On fresh surfaces the meta-andesite ranges from dark- to light-green; it weathers to brownish hues. Foliation is extremely varied. Along the western side of the unit, it is so strong that no vestige of the original texture and structure of the rock remains. Elsewhere it is moderate to weak. In outcrop the facies having the strongest foliation is a fine-grained spotted chlorite schist. The moderately foliated types strongly resemble much of the fine-grained meta-andesite tuff in the Iron King meta-andesite which overlies the Texas Gulch formation; however, sedimentary structures were not identified.

This type contains megascopic saussuritized plagioclase grains and chlorite. The meta-andesite with weak foliation appears more uniform and somewhat granular, and in places it contains small relict saussuritized plagioclase laths. In one locality the granular meta-andesite was seen to grade abruptly into a small body of more massive amygdaloidal meta-andesite that almost certainly represents a flow.

Chlorite is the dominant and omnipresent constituent of the unit. In places where it is not megascopic, its presence can be inferred from the color and luster of the foliation planes. Saussuritized plagioclase is prominent in the areas away from the strongest foliation. Characteristic dark-green to black spots in the chlorite schist facies may represent the incipient concentration of iron and perhaps magnesium.

Although the original rock of much of the unit cannot be identified, the composition is certainly andesitic, and probably both meta-andesite tuffs and flows are represented.

Green slate

Green slate, the western unit of the Texas Gulch formation, seems to be transitional to the overlying Iron King meta-andesite. It is 1000 feet wide near the southern limit of the region, but narrows northward either because of faulting against or overlap by the alluvium of Lonesome Valley.

The green slate is very fine grained and closely foliated; thus resembling the purple slate. Beds of medium-grained metatuff are intercalated here and there with the green slate. Clastic grains of saussuritized plagioclase and quartz in the metatuff are easily seen with a hand lens.

Sericite, chlorite, saussuritized plagioclase, and quartz are the characteristic megascopic minerals in the green slate. Their relative proportion varies widely, but sericite and chlorite can be recognized in nearly every outcrop.

IRON KING META-ANDESITE

Distribution

The Iron King meta-andesite, here named from the exposures around the Iron King mine, forms a north-trending belt about 18,000 feet wide in the south-central part of the Humboldt region. Recognizable beds dip steeply both eastward and westward but predominantly toward the west, and strike northerly. Alluvium of Lonesome Valley covers the northward extension of the formation for 8 miles from Humboldt to Grapevine Gulch in the Black Hills, 6 miles north of the area mapped. Near Grapevine Gulch the outcrop is less than 1/3 as wide as that exposed near Humboldt. Reconnaissance indicates that for a few miles at least the outcrop probably widens to the south at about the same rate as it thins northward.

The Iron King meta-andesite grades into the Texas Gulch formation to the east and into the Spud Mountain meta-breccia to the west. The contact between the green slate unit of the Texas Gulch formation and the Iron King meta-andesite is in places sharp and in other places gradational over a width of a few hundred feet. Megascopically the meta-andesite tuff in contact with the green slate contains more chlorite, less sericite, and is coarser grained and relatively more massive than the green slate.

In general the Iron King meta-andesite forms low rolling hills with a maximum relief of about 700 feet east of the Agua Fria River, of which about 200 feet of the relief occurs in the canyon of the Agua Fria.

Petrography

General features

The Iron King meta-andesite consists chiefly of meta-andesite flows and tuffs, but southeast of the Iron King mine it contains a unit of metarhyolite tuff and conglomerate 200 feet thick. Intrusive rocks invaded the formation, especially near the Agua Fria River and westward for about 3,500 feet. Local zones of hydrothermal alteration and larger quartz masses and veins were separately mapped and are shown on plate 1.

Though the metatuff and metaflow units are predominantly as indicated, small amounts of metatuff are intercalated in the metaflow units and conversely. However, large-scale interbedding between metatuff and metaflow within the units mapped is not believed likely. Commonly diagnostic exposures are scattered and intervening rocks were mapped as one unit unless marked differences in lithology, textures, or structures were recognized. In places differences in lithology were recognized but in areas too small to be recorded at the map scale used.

The textures and structures of the Iron King meta-andesite are predominantly metamorphic. The rocks are foliated but are easily cleavable only where chlorite is the dominant mafic mineral. Relict bedding, manifest chiefly by the distribution of the altered plagioclase, was recognized only in a few places in the metatuffs. Graded bedding and to a lesser extent channel and fill consistently indicate top toward the west, but were too few to prove that the top of the formation lies to the west in view of the possibility of intraformational folding.

Relict pillow structure was recognized locally in the meta-andesite flows, especially in more massive water-worn outcrops.

The meta-andesite tuffs resemble, both lithologically and mineralogically, some of the metatuffaceous parts of the Spud Mountain metabreccia and of the meta-andesite breccia in the Texas Gulch formation.

Chlorite is a universal constituent of the Iron King meta-andesite. It is associated with all other minerals and is believed to be entirely of metamorphic origin. The chlorite is pleochroic with X and Y green or bluish green and Z light yellowish-green to almost colorless. It generally shows an anomalous interference color of deep blue under crossed nicols. Chlorite constitutes as much as 60 percent of the more mafic rocks or as little as 10 percent of the more felsic. It occurs as fine flakes very intimately mixed with epidote minerals, albite, and quartz in the reconstituted areas of the rocks and is a common inclusion in the relict plagioclase associated with epidote minerals and sericite. The foliation of the rocks is dominantly due to aggregates of fine chlorite plates that form narrow bands that anastomose around the grains of quartz and feldspar. These bands probably represent concentrations of chlorite from adjacent rocks into zones, but chlorite occurs also as small, individual flakes, commonly in the same specimens. A few microveinlets of chlorite that cut relict feldspar were observed, and a few aggregates of chlorite plates have developed at an acute angle to the foliation.

Actinolitic hornblende occurs in both meta-andesite tuffs and flows and locally is the most abundant constituent of the rock. Its pleochroic formula is Z-blue green, Y-yellow green, and X-light yellow (almost colorless); Z to c ranges from 16° to 18°; and the birefringence appears prismatic grains crudely oriented parallel to foliation. The needles and grains occur both as scattered crystals and in aggregates forming zones relatively rich in actinolitic hornblende.

Epidote minerals abound in the Iron King meta-andesite making up from a few percent to perhaps as much as 60 percent of some of the meta-andesite flows. All but one of the thin sections of meta-andesites contain epidote and about half contain either clinozoisite or zoisite. Clinozoisite and zoisite are commonly indistinguishable because of their very fine grain. The epidote has normal birefringence and is light colored indicating a low iron content. Only a few crystals are recognizably pleochroic. The clinozoisite or zoisite commonly shows abnormal blue interference color.

The habit of the epidote minerals varies. Epidote commonly occurs in distinctly larger grains than either clinozoisite or zoisite, which are commonly so fine grained that 360 magnification is necessary for resolution. Aggregates of brownish epidote minerals commonly form pseudomorphs after the former plagioclase phenocrysts; they form also irregular-shaped masses. Most of the epidote minerals, however, occur as fine granoblastic grains less than 50 microns in diameter, intimately associated with quartz, albite, and chlorite.

The plagioclase ranges from albite (near Ab_{100}) to albite-oligoclase (near Ab_{85}). Albite occurs with assemblages containing chlorite as the dominant mafic constituent and albite-oligoclase with assemblages containing actinolitic hornblende as the dominant mafic mineral. The composition of the plagioclase was determined by refractive indices.

Inclusions of microscopic grains of chlorite, epidote, and sericite commonly cloud the plagioclase so that accurate determination of the refractive indices is very difficult.

Plagioclase occurs as microscopic granoblastic grains, and as albitized and saussuritized relict phenocrysts and detrital grains. It is most abundant and widespread as microscopic granoblastic grains intimately associated with epidote minerals, chlorite, and locally sericite. Saussuritized and albitized plagioclase is common. All gradations were observed between epidote-chlorite pseudomorphs after plagioclase, through epidote-chlorite-albite pseudomorphs, to nearly uncontaminated albite crystals that appear to have formed pseudomorphs after the original plagioclase, even preserving original twinning lamallae.

Quartz was found in all but two or three of the thin-sections examined, ranging from less than two percent to as much as 20 percent for different specimens. It occurs as rounded grains, amygdules, or as aggregates of granoblastic grains. It is these aggregates that form the megascopic quartz grains in the rocks. The individual founded grains are mostly granoblastic and microscopic and are associated generally with albite, epidote minerals, sericite, and chlorite.

In some of the metatuffs sericite is more abundant than chlorite. It occurs as very small flakes disseminated throughout the rock and as concentrations in ribbons that anastomose through the rock, curving around the larger grains or separating into bands on either side of the grains and commonly rejoining. The ribbons are composed of aggregates of sericite flakes oriented with their base in the foliation plane.

In typically meta-andesitic rocks almost all the sericite occurs as small, scattered, flakes within albitized relict plagioclase, probably being derived from the orthoclase in solid solution in the original plagioclase.

Carbonate was recognized in about half of the thin-sections of meta-andesites. Part is probably metamorphic and part probably post-metamorphic in origin. The metamorphic origin of some of the carbonate is suggested by attenuated quartz-carbonate amygdules, deformed and twinned grains of carbonate, and carbonate in the pressure shadows of relict plagioclase crystals, although this latter occurrence is not definite proof. Carbonate considered as post-metamorphic occurs with or without quartz in veinlets that are either parallel or transverse to foliation. It forms also irregular aggregates that commonly have their longer dimension perpendicular to foliation. In one section hornblende adjacent to quartz-carbonate knots and veinlets was altered to green chlorite. Much of the carbonate, however, occurs in disseminated small grains and aggregates, the origin of which is obscure.

Meta-andesite tuff

The meta-andesite tuff occurs in three lithologic units, (1) adjoining the Texas Gulch formation on the east, (2) in the central part of the formation, and (3) adjoining the Spud Mountain breccia on the west. Henceforth these units will be referred to as the eastern, middle, and western units. On fresh fracture the meta-andesite tuffs vary from green to gray-green, and weather to dull yellowish-green or brownish-green owing to the iron oxide formed from chlorite during oxidation.

Although foliation is pronounced, it varies in strength both within a single outcrop and in areas several thousand feet wide. In general, the finer-grained rocks are more regularly and better foliated, but in places it is difficult to determine whether the more pronounced foliation is due to an originally finer grain or to more intense shear. Fine- and medium-grained metatuffs are commonly interbedded on both large and small scales and locally bedding was recognized by preservation of sorting. In a few places graded bedding, cross bedding, and channeling were preserved. Chlorite-albite-epidote (or clinozoisite) constitutes the chief mineral assemblage in the western meta-andesite tuff unit, and to a lesser extent it occurs in the middle and eastern units. Hornblende-albite-oligoclase-epidote or clinozoisite is the dominant assemblage in the eastern part of the middle unit and in the western part of the eastern unit of meta-andesite tuffs. Chlorite-sericite-albite-quartz-carbonate is the dominant mineral assemblage in the eastern part of the eastern meta-andesite tuff unit. Along the southern margin of the map area biotite formed chiefly at the expense of chlorite, and one section contains colorless garnet.

<u>Chlorite-sericite-albite-quartz-carbonate meta-andesite tuff</u>: Chlorite-sericite-albite-quartz-carbonate is the dominant mineral assemblage in the eastern 3,000 feet of outcrops in the eastern meta-andesite tuff unit. Similar rocks are found also in the western part of the middle unit of meta-andesite tuffs, but are unknown in the western unit.

Some sections contained a little pyrite, and others contained leucoxene. The rocks contain a small amount of quartz that is not evident from megascopic examination. The quartz content of one specimen was estimated to be between 15 and 20 percent. The microscopic quartz forms granoblastic grains associated with granoblastic albite, small granules of epidote minerals, chlorite flakes, and in places sericite flakes. Megascopically visible quartz occurs as small "augen" composed of aggregates of granoblastic quartz grains. All the quartz is clear.

The albite (about Ab_{95}) occurs in microscopic granoblastic grains that commonly contain numerous inclusions, some of which are chlorite flakes; other included minerals are too fine grained to be recognized.

Chlorite is abundant. It occurs as disseminated flakes and as aggregates of fine flakes in small "ribbons" or bands that anastomose around the larger grains and "augen." Sericite is in general less abundant than chlorite, although in certain beds it predominates. Its distribution and habit is like the chlorite with which it is closely associated.

Carbonate in places constitutes by estimate as much as 15 or 20 percent of these rocks. It occurs as disseminated grains, irregular-shaped patches, and as veinlets associated with quartz.

A few small grains of zoisite or clinozoisite too small to distinguish were noted. The paucity of epidote minerals in these meta-andesite tuffs is in strong contrast to all the meta-andesite tuffs to the west, where commonly epidote minerals make up most of the rocks.

This condition probably indicates either that the original plagioclase was albite or that carbonate is a more stable form of lime-rich mineral under the temperature and stress conditions in which these rocks formed.

Although the metatuffs adjacent to the Texas Gulch formation have the same minerals as those to the west, the relative proportions are different. Quartz, sericite, and carbonate are much more abundant, and epidote minerals much less abundant; these differences may represent part of an original gradational change from the dominantly metarhyolitic Texas Gulch formation to the Iron King meta-andesite tuffs. The megascopic gradation shown in the green slate unit of the Texas Gulch formation and the variations in relative abundance of quartz, sericite, and chlorite from bed to bed supports this interpretation.

Along the south margin of the mapped area, the chlorite-sericite-albite-quartz assemblage appears to be passing into an assemblage containing biotite. The extent and characteristics of the biotite-bearing rocks are not known, as they were recognized in only three thin-sections. Two sections are characterized by a chlorite-biotite-albite (or oligoclase) assemblage and one by a biotite-sericite-quartz-grossularite assemblage. Magnetite and pyrite are minor constituents. The garnet is colorless or very light pink and has a refractive index of about 1.745, indicating a dominance of grossularite. The biotite is pleochroic in brown and light yellow-brown. It is associated with chlorite and in part derived from it.

Hornblende-oligoclase-epidote-meta-andesite tuff: Toward the west the chlorite-sericite-albite-quartz-carbonate metatuffs pass into hornblende-oligoclase-epidote meta-andesite tuffs. These latter rocks are less well cleaved than the chlorite-bearing rocks, owing to reconstitution of platy chlorite to nematoblastic actinolitic hornblende.

The actinolitic hornblende forms needles and fibrous plates crudely oriented with their long dimensions in the foliation. Epidote is more abundant than clinozoisite and occurs as porphyroblasts and as fine granoblastic grains scattered throughout the rock. Clinozoisite occurs chiefly in small disseminated grains. The plagioclase, generally sodic oligoclase, forms very small granoblastic grains and is not as abundant as the epidote minerals. Next to quartz-carbonate knots, actinolitic hornblende has been altered to a green chlorite that shows anomalous brown interference colors; this alteration suggests that the carbonate is late.

The hornblende-oligoclase-epidote meta-andesite tuffs are found near small gabbroic and dioritic intrusive bodies. Plate 1 shows the larger masses, but other masses, too small to be mapped, occur in the same general area. Meta-andesite flows, here associated with the metatuffs, also contain actinolitic hornblende as the dominant mafic mineral.

Chlorite-albite-quartz-epidote meta-andesite tuff and chlorite-albite-epidote meta-andesite tuffs: Chlorite-albite-quartz-epidote meta-andesite tuff and chlorite-albite-epidote meta-andesite tuffs are the most widespread and abundant metamorphosed tuffs in the Iron King meta-andesite. They compose all of the western meta-andesite tuff unit and parts of the middle and eastern. Fine- and medium-grained facies are interlayered in bands ranging in thickness from less than 1 inch to many feet. Foliation is more pronounced in the fine-grained bands, probably because of both more intense shear and finer-grained volcanic detritus. Mafic constituents appear more abundant in the finer-grained material than in the more granular adjacent rocks.

Chlorite and epidote minerals, generally pseudomorphous after plagioclase, are the chief megascopic constituents. Quartz can be recognized in some outcrops. Commonly most of the minerals are too fine-grained for megascopic recognition, although a greenish color indicates disseminated chlorite. In thin-section chlorite, albite, sodic oligoclase, carbonate, epidote, clinozoisite, zoisite, sericite, quartz, leucoxene, apatite, and a trace of orthoclase were identified; however, chlorite, albite, quartz, and epidote are the most abundant minerals. Chlorite composes from 15 to 60 percent of the rock; it occurs in microscopic flakes and in concentrations in wavy bands. Sericite occurs as scattered flakes in albitized relict detrital plagioclase crystals and also in bands like those of chlorite, but is much less abundant. The epidote minerals, consisting of epidote (most abundant), clinozoisite, and possibly zoisite, are very abundant and commonly associated in the rock. Most of the quartz is in microscopic, granoblastic grains but some of it is in aggregates of granoblastic grains, forming megascopic "augen." The plagioclase, chiefly in microscopic, granoblastic grains, is predominantly albite, but some is sodic oligoclase.

Meta-andesite flows

Meta-andesite flows occur in two units, separated by the middle meta-andesite tuff unit. The western meta-andesite flow is about 5000 feet in outcrop width and the eastern is 3500 feet. Where the dominant mafic mineral is chlorite the meta-andesite flows are well foliated, and where it is actinolitic hornblende they are relatively massive. Relict pillow structure was recognized in several places in the more massive eastern unit, particularly in the water-worn outcrops in the canyons of the Agua Fria and its tributaries. Amygdules are common and in foliated types are attenuated. The meta-andesite flows are much more uniform in fabric, mineralogy, and appearance than the meta-andesite tuffs and these features are most helpful in distinguishing the flows from the tuffs. Amygdules and pillow structure are diagnostic of a flow and though they are sporadic they confirm the other criteria for distinguishing these rocks from the tuffs.

The meta-andesite flows range from light green to dark green, being darker than the well-foliated meta-andesite tuffs. The flows are reconstituted completely into a mineral assemblage stable under conditions of low-grade metamorphism. Relict plagioclase altered chiefly to epidote minerals and chlorite is the dominant megascopic mineral. The actinolitic hornblende can rarely be recognized in hand specimens. In thin-section, chlorite, actinolitic hornblende, epidote, clinozoisite, albite or sodic oligoclase, carbonate, pyrite, quartz, and sericite are the minerals recognized. Both albite and epidote minerals form pseudomorphs after former plagioclase crystals. Much granoblastic clinozoisite and albite occur in microscopic grains in the finer-grained parts of the rock.

Chlorite-albite-epidote meta-andesite flows: Chlorite-albite-epidote-meta-andesite flows are all comprised in the western unit; they were not positively identified from the eastern unit, although they may occur there. They are amygdaloidal but do not contain recognizable pillows, possibly bedause the strong foliation destroyed them. Clinozoisite or zoisite occurs in addition to epidote and occurs as microscopic grains associated with chlorite and granoblastic albite. Most of the sericite is disseminated as flakes in the albitized phenocrysts. Granoblastic albite is less abundant than in the related meta-andesite tuffs and appears to range in composition from Ab_{90} to Ab_{95}. A small amount of granoblastic quartz is common.

Hornblende-oligoclase-epidote or clinozoisite meta-andesite flows: Hornblende-albite-oligoclase-epidote or clinozoisite meta-andesite flows occur only in the eastern band of meta-andesite flows. These rocks are more massive than the flòws to the west, because of the presence of actinolitic hornblende and to less deformation. Amygdules and pillow structures are common and do not appear to be appreciably deformed.

In addition to the characteristic minerals mentioned, carbonate, pyrite, and a trace of sericite are accessory minerals in the rocks. Actinolitic hornblende occurs as prismatic needles and fibrous masses, whose long dimension is parallel to the direction of crude foliation. Although the plagioclase ranges in composition from Ab_{85} to Ab_{95}, it is chiefly sodic oligoclase.

Metarhyolite tuff and conglomerate

Metarhyolite tuff and conglomerate form a unit, 200 feet thick, lying chiefly between the western meta-andesite flow and the upper meta-andesite tuff units. It is foliated and some of the pebbles in the conglomerate are attenuated so that lengths are many times greater than widths; while others are only slightly attenuated. Probably none of the original cobbles exceeded three inches in diameter, although the deformation makes difficult any estimate of original size. Near the Iron King mine the conglomeratic facies, occurring from 35 to 95 feet above the base, consists of interbedded conglomerate and metarhyolite tuff. Chalcedony, jasper, fine-grained leucocratic granitic rock, and an aphanitic siliceous rock whose origin is uncertain, comprise the types of cobbles and pebbles recognized. The upper part of the unit contains a few narrow beds of gray slate. One good exposure of graded bedding indicated that the top of the bed is toward the west.

The metarhyolite tuff and conglomerate is generally light gray but locally has a greenish cast because of small amounts of chlorite. It contains quartz (most abundant), sericite, feldspar, a little chlorite, and pebbles and cobbles as the megascopic constituents. In thin-section the metarhyolite tuff consists of abundant sericite, quartz, albite, and a trace of clinozoisite or zoisite. In some beds fragments of either rhyolite or rhyolite tuff are sheared out and altered to streaks of sericite and quartz.

The metarhyolite tuff and conglomerate appear to be lithologically identical to the metarhyolite tuff of the Texas Gulch formation. All the lithologic types found in the latter unit can be found duplicated in the former, and even the pebbles in the meta-conglomerate beds from the two units are similar.

SPUD MOUNTAIN METABRECCIA

Distribution

The Spud Mountain metabreccia, here named from Spud Mountain lying about one mile west of the Iron King mine, is exposed in a belt ranging from 4000 to 4500 feet wide in the western part of the area mapped (pl. 1). It is bounded on the east by a gradational contact with the Iron King meta-andesite and on the west by a pre-Cambrian fault now marked by a dike. On the southeast it is invaded by quartz diorite, and on the northeast it is overlapped by the alluvium of Lonesome Valley. The regional strike of the formation is N. 30° E. and the dip is generally steep toward the west. About ten miles north-northeast of the Iron King mine the Spud Mountain breccia crops out on the east side of Lonesome Valley in the low hills along the front of the Black Hills.

Stratigraphy

The Spud Mountain metabreccia consists of interbedded, metamorphosed volcanic breccia, lapilli tuff, and coarse and fine tuff in various amounts; metabreccia is most abundant. The chief mass of breccia stands out as a topographic high, forming Spud Mountain and similar hills along the strike extension southward. Metatuffaceous parts of the formation form topographic lows unless held up by interbedded breccia beds.

The base of the Spud Mountain metabreccia is gradational into the Iron King meta-andesite through interbedding of the lithologic types characteristic of the two units. The lowermost bed typical of Spud Mountain metabreccia was recognized just to the west of the Iron King veins (pl. 2). Most of the rocks, however, between this bed and the contact, as shown on plate 1, are typical of the Iron King meta-andesite and were included with that formation. It is impractical to map separately the various lithologic types in the Spud Mountain metabreccia on the scale used for the regional map, as interbedding between metabreccia and metatuffs occurs throughout the entire formation, the chief differences between areas being variations in relative amounts of each. Locally metamorphism was sufficiently intense to destroy the original texture and breccia structure so that breccia structures in a particular metabreccia bed are apparent in one locality but destfoyed in another. However, the general distribution of the chief lithologic types is known. The eastern half of the formation is characterizied by massive metabreccia beds interbedded with subordinate amounts of fine material in zones less than 100 feet in outcrop width. West of this zone lapilli-metatuff and metatuff increase in amount but metabreccia beds are common. The western 1000 to 1500 feet are predominantly metatuffs with interbedded metabreccia beds. This part of the formation is poorly exposed and partly covered by alluvium which adds to the difficulty of determining the relative amounts of rock types.

Two zones of meta-andesite flow were recognized in the Spud Mountain breccia. One, 150 to 250 feet in outcrop width, occurs about 750 to 800 feet west of the Silver belt-McCabe vein west of the Iron King mine. It could not be traced as far south as the road leading to the ghost town of McCabe. It consists of flow and flow breccia material. The other occurs from 200 to 300 feet east of the Silver belt-McCabe vein in the area south of the road to McCabe. This metaflow is more difficult to bound, and the thickness is not known.

Petrography

In outcrop the rocks vary from well-foliated and cleavable to massive types that have a pronounced foliation or planar structure but do not cleave readily parallel to that structure. In some exposures of metabreccia beds the fragments are not deformed perceptibly; in others they are so attenuated that lengths are 8 to 10 times the widths. The Spud Mountain metabreccia has two foliations, one striking from north to N. 30° W., the other from N. 20° E. to N. 35° E. Both dip at high angles westward. The significance of the two directions of foliation is discussed under structure.

Locally bedding is well preserved in the metatuffs and is particularly discernible in the larger gulches. Strikes range from N. 5° E. to N. 40° E. and the dips are generally steep toward the west. A few geopetal structures, largely graded bedding, indicated top toward the west.

Megascopically the metatuffs and metabreccias are green to gray-green on fresh fracture and various shades of yellow-green, browns, and reddish-browns on weathered surfaces. The megascopic minerals are chlorite, quartz, saussuritized plagioclase; and in places actinolitic hornblende can be inferred, although generally the hornblende is too fine-grained to be recognized with assurance under a hand lens. In places, especially in the metabreccia beds, the rocks are flooded with anastomosing veinlets of quartz and epidote. In places the fragmental character of the breccia beds is obscure. Beds of very obvious breccia grade along the strike into massive rocks in which no vestige of the original fragments remains. The original shape, size, and distribution of the original plagioclase crystals can be recognized long after the breccia fragments have disappeared possibly because the epidote minerals, which indicate the outline of the original plagioclase, are stable minerals under low-grade metamorphism.

The fragments in the metabreccia beds range from less than one inch to 18 inches in diameter and are composed of metarhyolite and meta-andesite. Fragments vary in size from one bed to another, but the size within individual beds is generally uniform. The metarhyolitic fragments are light-colored and contain relict quartz and saussuritized feldspar in a fine-grained ground mass. The meta-andesitic fragments are commonly amygdaloidal, light green because of their mafic constituents, and contain relict phenocrysts of saussuritized plagioclase. Other fragments are composed largely of quartz and epidote; their original composition is obscure.

In thin-section the rocks are seen to be composed of chlorite, actinolitic hornblende, epidote, clinozoisite, albite, quartz, sericite, trace of biotite, and leucoxene. The dominant minerals are chlorite, actinolitic hornblende, clinozoisite, albite, and quartz. Three assemblages were recognized: (1) chlorite-albite-clinozoisite (or epidote) with or without quartz, (2) actinolitic hornblende-albite-clinozoisite, and (3) actinolitic hornblende-chlorite-clinozoisite-albite. One bed in the transition zone between the Spud Mountain metabreccia and the Iron King meta-andesite is composed of chlorite and albite.

The habits and occurrences of the minerals in the Spud Mountain breccia are similar to those in the Iron King meta-andesite. Actinolitic hornblende occurs as oriented needles and bands of needles. Chlorite is disseminated as flakes intimately associated with microscopic granoblastic albite and quartz, and in saussuritized plagioclase. Epidote minerals occur in small disseminated granules and in large aggregates that commonly form pseudomorphs after the outline of plagioclase. Quartz forms microscopic granoblastic grains associated with epidote minerals, albite, and chlorite, and forms megascopic aggregates of granoblastic grains. Albite is the dominant plagioclase, but the composition of the plagioclase probably ranges from Ab_{95} to Ab_{85}. The albite occurs in irregular, microscopic granoblastic grains and as albitized plagioclase crystals that are pseudomorphic in form after the original plagioclase. Sericite is not abundant but is widespread as small flakes scattered throughout the albitized plagioclase crystals. A few flakes are commonly scattered throughout the reconstituted parts of the rocks. Leucoxene, in irregular shaped masses, is widespread but not abundant.

CHAPARRAL GULCH METAVOLCANICS

Distribution

The Chaparral Gulch metavolcanics, here named from the good exposures in Chaparral Gulch, are exposed in a northeast-trending belt in the western part of the area (pl. 1). Pre-Cambrian igneous rocks that were intruded along faults bound the Chaparral Gulch metavolcanics on the northwest and on the southeast; hence the thickness of the formation is not known, but its outcrop width ranges from 1500 feet to a little over 3500 feet. The extent of the metavolcanics to the northeast beneath the alluvium of Lonesome Valley is not known. It is not present between the Spud Mountain metabreccia and the Indian Hills metavolcanics where these rocks are seen six miles to the north on the east side of Lonesome Valley. The extent of the formation to the southwest has not been determined.

Stratigraphy

Because dikes, which were intruded along faults, bound the Chaparral Gulch metavolcanics, their age relations to adjacent formations are not known. Perhaps if the stratigraphic relationships of the formation were known, it would not merit formational rank.

The Chaparral Gulch metavolcanics are composed of interbedded metarhyolite and meta-andesite. Metarhyolite is subordinate to meta-andesite tuffs. In the section exposed meta-andesite tuff lies above and below the meta-rhyolites and forms both the top and bottom of the metavolcanics. An estimate for the exposed thickness in the southern part of the area is 1500 to 2000 feet. Shear has thinned units differentially to such an extent that any thickness estimates are only applicable locally. Bedding, determined from original sorting that is still visible in the distribution of saussuritized plagioclase, is parallel to foliation except in the crest of the anticline exposed in the southwest part of the formation. Two top determinations on graded bedding in the southern part of the unit indicated top to the east along the southeast edge of the Chaparral metavolcanics.

Petrography

The Chaparral Gulch metavolcanics were sheared more intensely than any other rocks in the district. They show a strong tendency for the micaceous minerals and quartz-albite to separate into individual bands. Many of the relict plagioclase crystals have been fractured into several parts that are now separated. Bands of very fine-grained granoblastic aggregates may indicate former mylonite zones.

Meta-andesite tuff

The meta-andesite tuff varies in texture, structure, and mineral composition, hence in physical aspect. The dominant type is characterized by the assemblage chlorite-sericite-albite-epidote-quartz; it is a fine-grained, very well foliated rock that varies in color from green or light green, to green with irregular patches and streaks of light-green and white. The color changes reflect the variation in relative amounts of the component minerals and even differences in the mineral assemblage itself. The mixture of subordinate amounts of rhyolitic material with the predominant andesitic detritus has produced the variations, and where rhyolitic material became dominant, it formed the metarhyolite tuff interbedded with the meta-andesite tuff. Some metarhyolite tuff beds, too thin to be mapped, are erratically distributed throughout the meta-andesite tuff. Quartz is in granoblastic grains or aggregates of granoblastic grains. Albite occurs in relict crystals enclosing microscopic grains of sericite, epidote, and chlorite and in microscopic granoblastic or cataclastic grains associated with quartz, chlorite, and epidote. Sericite, as concentrations in bands, is associated with chlorite, and occurs also as disseminated flakes in the albitized plagioclase crystals.

Interbedded with the meta-andesite tuff containing considerable sericite are beds characterized by the assemblage chlorite-albite-epidote, with only a little accessory sericite and quartz. These beds are dark green. They contain abundant megascopic saussuritized plagioclase and have a much less pronounced foliation. These beds are regarded as relatively pure meta-andesitic rocks. All gradations are found between them and the fine-grained, sericitic meta-andesite tuffs. Microscopically the meta-andesite tuffs are composed of chlorite, sericite, albite, epidote, clinozoisite, quartz, magnetite, and leucoxene. Microcline was not recognized but may be present.

Metarhyolite flow

The rocks here called metarhyolite flow may be in part metarhyolite tuff. The basis for calling them flow rocks is apparent relict flow banding in the northern exposures of the unit. The unit appears distinct from the metarhyolite tuffs, though the significance of the banding may be doubtful. The metarhyolite flow has a much less pronounced foliation and appears more granular. In thin-section it is seen to contain more feldspar and much less sericite than the metatuff. Although this feature does not prove the rock is a flow, the more felspathic rock has apparent flow banding and no recognizable sedimentary features, whereas the sericitic metarhyolite has sedimentary features but no flow banding.

The metarhyolite flow, characterized by the assemblage sericite-microcline-albite-quartz, is white to pink on fresh and weathered surfaces. It is foliated, but locally foliation is not prominent, especially where sericite is sparse. Quartz and feldspar, in grains not over one mm. in diameter, are the megascopic minerals.

Thin-sections show that the metarhyolite flow is composed of sericite, albite, microcline, quartz, and carbonate. Albite, microcline, and quartz occur both in residual megascopic crystals and in microcrystalline, irregular-shaped grains; sericite is in flakes. Carbonate occurs in sparsely disseminated grains.

It is not clear whether the plagioclase was originally albite or whether it was an intermediate plagioclase that was albitized during metamorphism.

Metarhyolite tuff

The metarhyolite tuff occurs in two units. The more westerly unit is white or rarely a light pink. The eastern band is most commonly light buff but locally contains sufficient chlorite to give some bands a greenish cast. The planar structure, which in places looks like foliation and in other places like bedding, is very even and closely spaced.

Quartz and feldspar are the only truly megascopic minerals, but sericite is obviously present, as indicated by the lustre and color of the cleavage planes of the rock. In section quartz and sericite are more abundant than microcline and albite; there is a trace of chlorite in the upper unit. Megascopic quartz, microcline, and albite blastoporphyritic crystals are set in a foliated microscopic matrix of cataclastic and granoblastic sericite, quartz, microcline, and a little albite.

INDIAN HILLS METAVOLCANICS

The Indian Hills metavolcanics, here named from the exposures in the Indian Hills in the Mingus Mountain quadrangle, occur in the northwestern part of the area, largely mapped by Krieger and Eckstein. The metarhyolites and meta-andesites crop out in north-trending bands about 2500 feet and 3000 feet wide respectively. They are bounded on the south by a fault contact, along which pre-Cambrian diorite was intruded, and are overlapped on the north by alluvium of Lonesome Valley. A large mass of diorite lies west of the metarhyolite. To the east the meta-andesite passes into dense, mafic metamorphic rocks (not shown on plate 1) whose origin is uncertain.

Northward-trending foliation is pronounced in the metarhyolite and the western part of the meta-andesite in all areas away from the southern contact with the diorite. As the southern contact is approached from the north, the foliation and formation swing from north to northeast, tending to parallel the contact. This change in attitude of the foliation is due either to drag along the pre-Cambrian fault or to the local development of a new foliation roughly parallel to the fault.

The metarhyolite is a fine-grained pink rock in which crystals of quartz and feldspar are visible in a microscopic matrix. In places banding suggestive of flow banding occurs. It is not known whether the metarhyolite represents lava, tuff, or a combination of both. A thin-section from the small band of metarhyolite south of latitude $34^{\circ} 30'$ is composed of 60 percent quartz, 30 percent potash feldspar, and 10 percent sericite. The quartz and feldspar occur in granoblastic grains, commonly separated by cataclastic zones. The sericite occurs in flakes. The texture closely resembles that of an aplite. Toward the east the metarhyolite grades into the meta-andesite.

The meta-andesite is dark green. It is composed of meta-andesite flows, meta-andesite flow breccia, and some metatuffaceous sediment. Amygdules of quartz and carbonate are common and widely distributed in the metaflows, and pillow structures were recognized at one locality. Metamorphosed flows are more abundant in the eastern part of the unit. Westward, interbeds of metasediments increase in abundance until they predominate over flows.

ORIGIN OF THE PRE-CAMBRIAN METAVOLCANIC ROCKS

The following table summarizes the common mineral assemblages recognized in the pre-Cambrian metavolcanics.

Table 1.--Common mineral assemblages in pre-Cambrian metavolcanics

1.	Chlorite-albite-epidote-clinozoisite	meta-andesite breccia	Texas Gulch formation
2.	Quartz-sericite	metarhyolite tuff	
3.	Chlorite-sericite-albite-quartz-carbonate	meta-andesite tuff	Iron King meta-andesite
4.	Actinolitic hornblende-oligoclase-epidote	meta-andesite tuff and flow	
5.	Chlorite-albite-epidote (with or without quartz)	meta-andesite tuff and flow	
6.	Sericite-quartz-albite	metarhyolite tuff	
7.	Chlorite-albite-clinozoisite or epidote-quartz	metabreccia and tuff	Spud Mountain metabreccia
8.	Actinolitic hornblende-albite-clinozoisite	do	
9.	Actinolitic hornblende-chlorite-albite-clinozoisite	do	
10.	Chlorite-albite	do	
11.	Chlorite-sericite-albite-epidote-quartz	meta-andesite tuff	Chaparral Gulch metavolcanics
12.	Chlorite-albite-epidote	do	
13.	Sericite-microcline-quartz-albite	metarhyolite tuff and flow	

In large part the mineral assemblages comprising the meta-andesites and metarhyolites represent dynamothermal metamorphic facies derived from normal volcanic rocks under low temperature and moderate stress. Certain of the assemblages, notably 3, 10, and 11 in Table 1, may require some special explanation.

The metamorphism of much of the meta-andesite tuff, all the meta-andesite flows, the Spud Mountain metabreccia, and the meta-andesite breccia of the Texas Gulch formation have yielded mineral assemblages (1, 4, 5, 7, 8, 9 and 12 of Table 1) which are expectable from andesitic volcanics. Turner (1948, p. 52) utilized the following schematic representation to indicate the transformation of basic igneous rocks under low-grade conditions into stable metamorphic derivatives that are similar to those referred to in Table 1:

Augite (or hornblende) + plagioclase + ilmenite + water = actinolite + chlorite (aluminous) + epidote + albite + sphene, or = chlorite + epidote + albite + sphene (with minor quartz).

Harker (1939, pp. 280-281) gives essentially the same assemblages as being the normal products of low-grade regional metamorphism of basic lavas and tuffs, and Eskola (1939, pp. 357-359) classifies rocks with these metamorphic assemblages under his greenschist facies and indicates that the minerals are stable under conditions of low temperature and moderate stress. Hutton (1949, p. 50) states that the greenschist of Western Otago, New Zealand, which includes albite-epidote-chlorite and albite-epidote-actinolite schists are the results of low-grade dynamothermal metamorphism of basic igneous rocks. He has furnished additional proof (Hutton 1940, p. 51) by two chemical analyses. The analysis of an albite-epidote-actinolite-chlorite schist is reasonably close to that of a quartz gabbro, whereas an actinolite-chlorite-albite schist was remarkably similar chemically to a basalt.

The metamorphic assemblages developed from metarhyolites are given by 2, 6, and 13 of table 1. The products of low-grade metamorphism of rhyolitic rocks are predictable from a knowledge of the bulk composition and the minerals stable under those conditions. The following schematic representation indicates the mineralogical transformations:

Plagioclase + orthoclase + quartz + biotite (small amount) + CO_2 + water = albite + quartz + sericite + carbonate + chlorite (small amount).

Apparently potash feldspar can occur with the products as a relict or can be converted completely to sericite. In general the metarhyolites consist of normal mineral assemblages in the correct proportions, but some possible variations are noteworthy. The metarhyolite tuffs and flows in the Chaparral Gulch metavolcanics do not contain any visible carbonate and the thin-sections show only a trace. It seems possible that the original plagioclase may have been albitic. If so, the original rocks were probably quartz keratophyres instead of rhyolites. However, the solubility of carbonate is so great with respect to other minerals present that the possibility of removal of the carbonate in solution exists. None of the metarhyolites contains more than a trace of chlorite which probably reflects a very low mafic content in the parent rocks.

The assemblages represented by 3 and 11 of table 1 represent bulk compositions intermediate between that of the meta-andesites and metarhyolites previously discussed. The field occurrence of these rocks suggests that they represent a mixture of rhyolitic and andesitic tuffaceous sediments. The chlorite-sericite-albite-quartz-carbonate assemblages in the eastern metatuff member of the Iron King meta-andesite grades into the dominantly rhyolitic purple slate and metarhyolite tuff units of the Texas Gulch formation through a green slate that contains an abundance of both sericite and chlorite. The western part of the Texas Gulch formation has here and there slightly chloritic bands that appear to anticipate the gradational change into the Iron King meta-andesite. In the lower metatuff unit of the Iron King meta-andesite irregularities in the relative amounts of the mineral constituents from bed to bed suggest a mixture of detritus from different sources. Quartz and orthoclase or potash-bearing clay minerals were probably the parent minerals for the quartz and sericite in the eastern tuff unit. The presence of biotite, which results from reaction between sericite and chlorite with increase in the grade of metamorphism, indicates the presence of available potash. The lack of potash in strictly andesitic rocks resulted in the formation of actinolitic hornblende in place of biotite under similar grade conditions. The paucity of epidote minerals indicates either original albitic plagioclase or metamorphic conditions of the lowest grade in which carbonate was formed in place of epidote minerals.

There is little doubt that the chlorite-sericite-albite-epidote-quartz assemblage in the Chaparral Gulch metavolcanics represents a mixture of andesitic and rhyolitic detritus, as all gradations between the two types exist. Although meta-andesite predominates, metarhyolite detritus occurs in beds ranging in width from a few millimeters to several hundred feet (pl. 1).

Microscopic studies have yielded some information on the reactions by which the metamorphic minerals were formed. Albite and albite-oligoclase occur in two habits, as microscopic granoblastic grains and as albitized relict plagioclase. The granoblastic habit is characteristic for low-grade metamorphic rocks and results from the separation of the albite component in plagioclase with the simultaneous production of epidote minerals. No disagreements exist as to the general character and end products of the reaction, plagioclase + water = albite + epidote minerals, but the precise chemical method by which the transformation is accomplished is much debated. In thin-section aggregates of albite and epidote minerals (with or without small amounts of sericite and chlorite) that retain the crystal form of plagioclase indicate the reality of the process.

That plagioclase crystals have been albitized is shown by microscopic evidence alone. Thin-sections of meta-andesite flows show relict plagioclase crystals that have the crystal habit and broad twinning characteristic of phenocrysts in andesites, but are albitic in composition. To a lesser extent, sections of meta-andesite tuff show similar features. Although some crystals are quite clear except for scattered flakes of sericite, others contain various amounts of epidote minerals. The crystals preserved by albitization represent only part of those originally present, and commonly are those that lie with their long dimension parallel to foliation. All the feldspar shows cataclastic effects. All gradations of fracturing, displacement, and granulation exist between the best preserved crystals which are granulated only around the periphery to those whose original occurrence can be surmised only from a lenticular streak of granoblastic grains. The crystals that lie transverse to the foliation are disturbed the most and only a few whose long axes originally made angles of more than 30° with foliation have survived. On the other hand, masses of epidote minerals, without a trace of associated albite, preserve the outline of the original plagioclase crystals. Microscopic granoblastic albite also is present. Hence it would appear that some plagioclase crystals were destroyed completely, with the sodium and some silica being utilized for albitization and granoblastic albite, while calcium, aluminum, oxygen, and the remaining silica combined with water and possibly iron to form clinozoisite or epidote. The albitization would require the replacement of aluminum by tetravalent silicon. This reaction would release additional calcium and alumina which would unite with additional silica, oxygen, and water to form clinozoisite. However, calcium is in excess of the amount necessary to combine with aluminum to form clinozoisite. It must either react with CO_2 to produce calcite or be removed. The fine granular clinozoisite (or zoisite) so common in many of the sections could form in this way. Although the process outlined is theoretical and only a possibility, it does utilize the original components to produce the existing minerals in the form in which they are known to exist, and it does not require the introduction of material from an outside source.

In the Iron King meta-andesite actinolitic hornblende occurs in a broad band through the central part of the formation. The igneous rocks in this area, which may have been intruded during the metamorphism, probably account for the higher temperatures indicated by the local development of actinolitic hornblende. The actinolitic hornblende in the Spud Mountain metabreccia is more difficult to explain. Perhaps it is related to some unexposed offshoot of the large mass of granodiorite to the southwest. The presence of both chlorite and actinolitic hornblende in some assemblages possibly may be accounted for by the amount of available quartz besides the obvious explanation of incomplete equilibrium. Free quartz is present in assemblages containing chlorite and is absent in the assemblages containing actinolitic hornblende. As actinolitic hornblende forms from chlorite by the addition of lime and silica, possibly the abundance of available lime and silica governed the amount of actinolitic hornblende formed. Under such conditions chlorite and actinolitic hornblende could exist together and represent equilibrium conditions.

The assemblage chlorite-albite (assemblage 10, table 1), which occurred in the transition zone between the Iron King meta-andesite and the Spud Mountain breccia is abnormal. It could form in several ways, all of which involve removal of lime prior to or contemporaneous with metamorphism. The removal of lime results in a relative enrichment in soda and consequently albitization. The local floods of quartz-epidote veinlets in certain zones in the Spud Mountain metabreccia shows that lime and alumina migrated.

Pre-Cambrian intrusive rocks

GRANITE AND ALASKITE

Two masses of granite and one of alaskite occur within the area shown on plate 1. The granites occur along the eastern and western edges of the area, and the alaskite is in the north-central part.

The granite mass in the eastern part was mapped only along its western contact; its extent to the east is unknown. On the north it is bounded in part by gabbro, and on the west and southwest it is in contact with quartz porphyry. The granite is probably younger than the quartz porphyry, but its age relation to the gabbro is uncertain. It lies along the western margin of a large mass of the Bradshaw granite, as described by Jaggar and Palache (1905, pp. 3-4). In this area the Bradshaw granite is chiefly granodiorite and the granite may represent a local variant.

In outcrop the eastern granite is a light buff color. It weathers to rounded, more-resistant masses that are separated by areas of no exposures, which are covered by residual decomposed granitic debris. The granite is coarse grained hypidiomorphic granular. It contains about 5 percent (by estimate) of biotite, some plagioclase, and abundant potash feldspar and quartz. The granite was not studied microscopically.

The granite mass in the western part of the area mapped is bounded by diorite and gabbro. According to Krieger and Eckstein (oral communication), who mapped the northern part of this mass, pegmatitic offshoots from the granite cut the adjacent diorite and gabbro, indicating that the granite is younger. This granite is a medium-grained rock, and local areas in hand specimens have a relict hypidiomorphic granular texture. Biotite, albite, potash feldspar, and quartz are the dominant constituents. Potash feldspar is about twice as abundant as albite; quartz comprises up to 30 percent of the rock, and biotite from 5 to 10 percent. Sericite and leucoxene are accessory minerals. The textures of the granite have been modified considerably by deformation, but an igneous texture is still dominant. Quartz is in large part granoblastic. Both potash feldspar and albite in places have mylonitic finely granulated boundaries and small zones of mylonite are localized at the common intersections of several grains. The cores of the feldspar, however, have not recrystallized. Some granulation has occurred along small fractures.

The alaskite crops out in a small area in the north-central part of the area; it is bounded on three sides by the Chaparral Gulch metavolcanics and is overlapped on the north by the alluvium of Lonesome Valley. The alaskite is well foliated, perhaps more so than any other granitic igneous rock in the district except the granodiorite dikes intruded along the faults bounding the Chaparral Gulch metavolcanics.

Alaskite porphyry forms a border facies along the southwestern part of the alaskite. Angular fragments of feldspar and quartz with smaller amounts of sericite form the dominant megascopic constituents. Although the alaskite was not studied microscopically, the quartz and probably part of the feldspar has recrystallized.

The age relations of the granite and alaskite to other pre-Cambrian rocks in the district are only partly known. The granite, alaskite, and the granodiorite, which will be described in the following section, are all part of the Bradshaw granite, a general unit described by Jaggar and Palache (1905) for the vast amount of granitic rocks that occur in the Bradshaw mountains. Jaggar and Palache (1905 , p. 4) describe two modes of occurrence for diorite, one, as a marginal facies of the Bradshaw granite, and two, as independent bodies. They relate the first occurrence, with justification, to the Bradshaw granite, but for the second they do not exclude the possibility of a different period of intrusion. The granite in the western part of the Humboldt region is younger than the diorite and gabbro in which it occurs, as previously described. But whether or not this represents the general case will have to await additional field work in the district. There are reasons based on structure for believing this diorite-gabbro body may be older than others in the Humboldt region.

GRANODIORITE AND QUARTZ DIORITE

Mapping in the granodiorite area was limited to tracing the contact of this rock and the adjacent metavolcanics. The small mass of granodiorite in the northeast and the quartz diorite in the southwest corner of the Humboldt region (pl. 1) both increase in outcrop width into large bodies of medium- to coarse-grained rock.

The granodiorite in the northeast corner of the region is a medium- to coarse-grained, hypidiomorphic granular rock. Hornblende and biotite are the characteristic mafic minerals. Quartz is abundant, constituting by estimate about 25 percent of the rock. Potash feldspar occurs as large pink crystals; plagioclase, more abundant than potash feldspar, is white and commonly shows polysynthetic twinning. As exposed along the road to Cherry, the granodiorite appears relatively uniform for perhaps ten miles from its western border.

The quartz diorite, exposed in the southwest corner of the region, is a light-colored, medium-grained, granitic rock. Here and there around the margins it is deformed, sufficiently so that a crude foliation has developed. The dike of quartz diorite along the eastern boundary of the Chaparral Gulch metavolcanics has been sheared strongly, and it possesses a pronounced foliation. As a rough approximation, the marginal quartz diorite contains from 20 to 25 percent mafic minerals, from 15 to 20 percent quartz, and from 50 to 60° percent feldspar; plagioclase appears to predominate greatly over potash feldspar. Away from the margins, which are appreciably altered, the rock is probably a hornblende-biotite-quartz diorite. In the marginal rocks biotite, pleochroic in deep green and light brown, is altered partly to chlorite, and green hornblende to chlorite and biotite. The plagioclase is saussuritized; the relict grains consist of abundant epidote and clinozoisite (?), chlorite, and sericite, all set in a base of albite. Here and there less saussuritized oligoclase occurs as small grains or parts of larger crystals. Orthoclase occurs in irregularly shaped grains. Quartz is fractured and strained, and commonly exhibits cleavage or regular fractures as a result of the deformation. Accessory apatite is common.

No distinction between granodiorite and quartz diorite was made for the dike rocks (qd) that partly bound the Chaparral Gulch metavolcanics and for the mass (qd) in the north-central part of the Humboldt region, for these rocks are too strongly deformed and altered for one to distinguish between the two types on the bases of megascopic examination and a few thin-sections. They are grouped under quartz diorite because of their close spatial relation to the quartz diorite mass in the southwestern corner of the Humboldt region and because one of the dikes appears to be an offshoot of the quartz diorite. The megascopic constituents of the sheared quartz diorites are quartz, sericite, fragments of feldspar, and, rarely, a little chlorite. In places the planar structures are so well developed that the rock is schistose. Toward the southwest the degree of shearing gradually diminishes as the main mass of quartz diorite is approached.

The age of the granodiorite and quartz diorite is believed to be the same as that of the granite, discussed in the preceding section, as this granite, so far as known, is a local facies variation of the granodiorite.

DIORITE, QUARTZ DIORITE, GABBRO, AND DIABASE

Mafic, holocrystalline, intrusive rocks, including quartz diorite, gabbro, and diabase are widespread throughout the region mapped, commonly in small masses (pl. 1). Some of the masses are megascopically homogeneous in mineral composition and texture, whereas others have a considerable range in both composition and texture. In places where shearing and alteration were pronounced, the writer was unable to distinguish between diorite and gabbro. The following table summarizes the rock types recognized.

Location	Rock type recognized
1. East-central margin of Humboldt region	1. Gabbro
2. Small mass in meta-andesite breccia, Texas Gulch formation	2. Diorite porphyry
3. Central part of Iron King meta-andesite	3. Gabbro, diabase
4. Dike bounding east side of Chaparral Gulch metavolcanics	4. Diorite and quartz diorite, gabbro (?)
5. Dike bounding west side of Chaparral Gulch metavolcanics	5. Diorite, gabbro (?)
6. West-central margin of Humboldt region	6. Diorite, gabbro, diabase

Diorite and quartz diorite form relatively homogeneous masses in the dike bounding the east side of the Chaparral Gulch metavolcanics. These masses are chiefly diorite, but near the margins the diorite locally grades into a border facies of quartz diorite. These rocks generally do not show a megascopic foliation, but metamorphism has destroyed completely the original igneous texture. They have a medium grain but contain irregular blebs as much as 8 mm. in diameter of (1) aggregates of epidote minerals and plagioclase, (2) areas in which actinolitic hornblende is concentrated. The rest of the rock appears granular. The rock is composed chiefly of granoblastic quartz, epidote, clinozoisite, and plagioclase (Ab_{80-85}), platy chlorite, and fibrous actinolitic hornblende.

Mafic diorite is dominant in the dike that bounds the Chaparral Gulch metavolcanics on the west, but some gabbro may be present. It has a pronounced planar structure that in section is seen to be due to irregular cataclastic zones. The mafic diorite is medium grained and contains megascopic saussuritized plagioclase, fibrous hornblende, and here and there chlorite and a little quartz. The original igneous texture is mostly gone, but the saussuritized plagioclase locally is still somewhat tabular in outline. A specimen from a mafic diorite dike consisted of actinolitic hornblende (30 percent), epidote, clinozoisite, albite, and perhaps a few small residual grains of augite. Albite grains, some of which are twinned, are fractured and serrated around the boundaries; very fine granoblastic albite occurs in the interstices between larger grains. Actinolitic hornblende is in porphyroblasts and disseminated fine needles. The epidote minerals are granoblastic.

Although diorite is probably the dominant rock type in the mass in the west-central part of the Humboldt region, diabase and gabbro also were recognized. Mapping by Krieger and Eckstein to the northwest has shown that these rocks form a large, complex mass of mafic intrusive rocks. Planar structures in the rock are not pronounced. In outcrop the diorite is a medium-grained rock composed of irregular blebs of saussuritized plagioclase as much as 2 mm. in diameter, mafic constituents, and epidote minerals. In section plagioclase, clinozoisite, actinolitic hornblende, and small amounts of chlorite, sericite, and quartz were recognized. Pyrite and apatite are minor accessories. The plagioclase is locally saussuritized to epidote minerals, chlorite, and sericite. In some crystals alteration is not pronounced, and the plagioclase is andesine (near Ab_{50}). In other places plagioclase is granoblastic and apparently much more albitic. The actinolitic hornblende, as much as 3 mm. in diameter, is porphyroblastic, enclosing other minerals. Some actinolitic hornblende has rims of nonfibrous brown hornblende. Clinozoisite is in small granoblastic grains and aggregates.

The diorite porphyry in the meta-andesite breccia unit of the Texas Gulch formation consists of relict saussuritized plagioclase phenocrysts and irregular blebs of mafic minerals in a fine-grained, light green, granular groundmass.

The gabbro in the east-central part of the Humboldt region between the granodiorite and granite appears uniform in texture and composition in the small part of the mass mapped. The gabbro is medium- to coarse-grained and locally has a gabbroic texture. In outcrop it consists of subhedral plagioclase and irregular-shaped areas of mafic minerals, probably hornblende and residual augite.

The intrusive rocks in the central part of the Iron King meta-andesite are chiefly gabbro; however, some ultrabasic types may be present, for in places no feldspar was recognized. These intrusive masses are foliated, owing to the presence of oriented fibrous actinolitic hornblende, but not especially cleavable. In outcrop the gabbro is medium- to coarse-grained and contains fibrous hornblende and granular, saussuritized plagioclase. The gabbro is reconstituted completely. In section actinolitic hornblende, epidote, clinozoisite, and albite are the major constituents. Actinolitic hornblende, commonly the dominant mineral, occurs both in fibrous porphyroblastic grains with ragged terminations as much as 4 mm. in diameter, and in slender curved wisps and needles. Granoblastic epidote and clinozoisite are abundant as fine grains and aggregates. Some granoblastic albite occurs, but it is subordinate to the actinolitic hornblende.

Diabase, widespread in the region, as indicated in the above table (see p. 65), occurs chiefly in small, irregular-shaped masses and dikes. The writer has used relict diabasic texture to distinguish diabase from other fine-grained, mafic intrusive rocks. The relationship of diabase to the associated mafic rocks is commonly obscure. No sharp contacts between diabase and gabbro were recognized in the mafic masses in the central part of the Iron King meta-andesite or the diorite-gabbro along the west-central margin of the Humboldt region. Diabase dikes that appear to be offshoots from the composite dike bounding the east side of the Chaparral Gulch metavolcanics cut the Spud Mountain meta-breccia.

The mafic intrusive rocks described in this section of the report are clearly intrusive into the Yavapai series. However, their age in relation to the granite and granodiorite comprising the Bradshaw granite, discussed in the section on granite and alaskite, is not known with assurance. In the west-central part of the Humboldt region pegmatitic dikes, originating from the granite, cut the diorite and gabbro, but this constitutes the only clear-cut age relation between these two rock types known to the writer. There are reasons, discussed under structure, for believing these diorites and gabbros may be older than others exposed in the region. The additional mapping being done in the Prescott quadrangle by Krieger and Eckstein probably will establish age relations in this general area.

METARHYOLITE (?)

The metarhyolite occurs in the Texas Gulch formation, within the meta-andesite breccia and between the metabreccia and coarse-grained intrusives. It has a very irregular outcrop pattern that in many places crosscuts the regional strike of the meta-andesite breccia.

The metarhyolite has a poor cleavage which cannot be related to the orientation of minerals. The rock is light-colored, either cream-colored or white. Megascopically it is composed of a felsitic groundmass with sparse relict quartz and feldspar phenocrysts. Secondary pyrite in veinlets and disseminated crystals are commonly scattered throughout the extent of the unit, and where pyrite is abundant, the metarhyolite is streaked with iron oxide. In thin-section the metarhyolite consists of relict phenocrysts of quartz and euhedral albite in a microcrystalline groundmass. A little chlorite in irregular masses also is present. One quartz grain has the smooth indentations characteristic of partly resorbed quartz seen in some rhyolitic rocks. The albite crystals have remarkably good crystal forms in both complete crystals and in parts of crystals. Several crystals with perfectly developed crystal outlines have cores of groundmass material, and in others the crystal faces are developed on three sides, as seen in sectional view. The groundmass consists of a microcrystalline aggregate. Under high magnification individual grains have highly serrated outlines; they extinguish in an undulatory fashion that is reminiscent of devitrified glass.

Sericite is liberally sprinkled throughout the rock. It appears to replace chlorite, penetrates quartz grains, and rims the albite crystals, all habits that suggest a secondary origin.

The metarhyolite is a very puzzling rock. Where first mapped the field relationships suggested that it was intrusive, but the widespread indications of alteration suggested that it might be a product of hydrothermal alteration of the meta-andesite breccia. Microscopic study, however, gives no indication of a genetic relationship to the meta-andesite breccia. The textures appear compatible with an intrusive origin.

QUARTZ PORPHYRY

Quartz porphyry crops out in a small dike-like body about 700 feet wide in the central part of the Iron King meta-andesite and in a larger mass between the granite and the meta-andesite breccia unit of the Texas Gulch formation. Several small bodies of the quartz porphyry occur in the meta-andesite breccia to the west of the main mass.

The quartz porphyry in the Iron King meta-andesite is well foliated, and the western margin and outlying bodies of the eastern occurrence of quartz porphyry are more or less foliated, whereas the interior part is more massive.

The quartz porphyry is composed of as much as 30 percent of rounded relict phenocrysts of quartz and lesser amounts of albite in an aphanitic groundmass. Where well sheared, the groundmass contains megascopic sericite. In thin-sections of well-sheared specimens, the quartz phenocrysts are seen to be fractured and strained; some appear to have been sheared out and recrystallized into lenticular aggregates of granoblastic quartz. The crystals of albite, where not modified by cataclasis, are euhedral, and commonly show closely spaced polysynthetic twinning. The groundmass is composed of granoblastic quartz and albite, and of abundant sericite that occurs as disseminated, oriented flakes and as "ribbons" that wind through the rock. Potash feldspar was not recognized in the sheared facies of the quartz porphyry; presumably it was all transformed into sericite.

Locally at least, the rocks along the western margin of the eastern mass are believed to be albitized, as indicated by a great variety of symplectic textures between quartz and albite. This feature is described elsewhere. The quartz porphyry in the southeasternmost exposures apparently has been contaminated, for locally it contains up to 30 percent by estimate of mafic minerals, which appear to include hornblende, biotite, and chlorite.

The quartz porphyry invades the Iron King meta-andesite and the meta-andesite breccia unit of the Texas Gulch formation, but itself is cut by diorite. It is probably older than the granite, as the quartz porphyry is sheared appreciably near the granite, and the granite is not. Although the granite and the quartz porphyry have a "frozen" contact, neither cutting of one by the other nor contact chilling was seen.

Cenozoic rocks

MINGUS MOUNTAIN BASALT

The Mingus Mountain basalt, here named from the excellent exposures of this rock on Mingus Mountain in the Mingus Mountain quadrangle, consists of basalt and subordinate basaltic sediments. Mingus Mountain basalt occurs in a large patch in the central part of the Humboldt region, and in several small patches on the downthrown side of the normal fault that bounds the east side of Lonesome Valley. One small patch caps a hill, just east of the Agua Fria River, southeast of Humboldt. Large areas in the Bradshaw quadrangle and much of the summit area in the Black Hills toward the northeast are covered by basalt. All the patches are remnants of a basalt blanket that was widespread over this part of Arizona.

The basalt is a dense, black to dark-gray, vesicular flow rock with interbedded flow breccia. Basaltic sediments occur only in the large exposure south of Humboldt. They are well-bedded basaltic sands and gravels that probably filled irregular depressions on the surface during the period when vulcanism was active. Such sediments are common in the basalts that cap Mingus Mountain in the Black Hills, twenty miles to the northeast. The basaltic sediments near Humboldt crop out along the north wall of the stream canyon that bisects the exposure of basalt. Southward they pinch out and the basalt rests on unconsolidated gravels.

The basalt is porphyritic, with phenocrysts of olivine and augite in a hypohyaline groundmass containing microscopic plagioclase laths.

Though the age of the basalt is uncertain, it antedates the faulting along the east side of Lonesome Valley, and hence the present topography of the district. Mr. Kendall of the Ground Water Branch of the U. S. Geological Survey found vertebrate remains in the gravels near Prescott, Arizona. As the gravels are interbedded with basalt flows, it is quite possible that these lavas and gravels are essentially contemporaneous with those at Humboldt, which are about 12 miles from the Prescott occurrence. Dr. C. L. Gazin of the National Museum, Washington, D. C., tentatively dated the vertebrate remains as Pliocene or Pleistocene, the assemblage not being diagnostic of any smaller time interval. Hence, a questionable age of Pliocene or Pleistocene is the best that can be assigned to the Mingus Mountain basalt at this time.

ALLUVIUM

Alluvium of Lonesome Valley is widespread in the central part of the Humboldt region. Small erosional remnants of gravels occur in the southwest part of the region, well above Lonesome Valley.

At least three different gravels are represented under the heading alluvium. The youngest gravels form the river wash along the Agua Fria River and tributary streams. The gravels of intermediate age constitute the fill of Lonesome Valley; this fill is now being dissected as the Agua Fria deepens its canyon in the pre-Cambrian bedrock downstream. The oldest gravels are interbedded with the Mingus Mountain basalt.

The oldest gravels, exposed beneath the basalt south of Humboldt, are unconsolidated and unsorted boulders, gravels, and sands. Generally the pebbles and boulders are rounded to subrounded. Basaltic types predominate, but pre-Cambrian and Paleozoic rock types also are well represented.

The gravels of intermediate age, best exposed in the walls of the Agua Fria River in Lonesome Valley, are crudely bedded. Beds composed of gravel and boulders alternate with thicker units containing sand-, silt-, and clay-size particles. The gravel and boulder beds in part may represent stream channels, for in Lonesome Valley certain wells, which draw much water from a gravel bed far above bedrock, are arranged in a line. Giant cottonwood trees were the guide to this water channel. The gravels and boulders in the fill of Lonesome Valley comprise basalt and Paleozoic and pre-Cambrian rock types. The ratio of basalt to other rock types is lower in the gravels of intermediate age than in the gravels interbedded with the basalt.

The Recent river wash is the material being carried down and deposited by the ephemeral streams draining the district. In general it is heterogenous but consists chiefly of pre-Cambrian rocks. Sand-sized and larger fragments are all that are deposited; the finer material is carried away.

The age of the alluvium varies from Pliocene (?) or Pleistocene (?) to Recent. The alluvial fill of Lonesome Valley is probably chiefly of Pleistocene age. Lonesome Valley certainly received sediments as the result of movement along the fault on the eastern side of the valley. As this fault offsets the basalt, valley fill must have accumulated in post-basalt time, probably including at least part of the Pleistocene epoch. The remnants of gravels perched on the lower slopes of the hills adjacent to Lonesome Valley and the terraces in the valley show that erosion has been active for a considerable time, probably since some time in the Pleistocene.

STRUCTURE

General features

The structure of the Humboldt region is complicated, so much so that the evidence for some of the structural elements is not found within the small area mapped, and for others only a tentative explanation can be offered.

All the pre-Cambrian rocks are foliated, except the interior parts of the larger intrusive bodies. The foliation has two major trends, (1) north to N. 20° W. and (2) N. 20°-45° E. The north- to northwest-trending foliation is dominant in the Indian Hills metavolcanics and in the Spud Mountain metabreccia, and the northeast-trending foliation is dominant in the Iron King meta-andesite, Chaparral Gulch metavolcanics, and Texas Gulch formation. To a lesser extent the northeast-trending foliation also occurs in the Spud Mountain metabreccia, and is superimposed--locally in individual outcrops--on the north-trending foliation. Either the deformation contributing to the northeast-trending foliation occurred in two periods, separated, locally at least, by intrusion of igneous rock, or igneous rocks were intruded during the period when the deformation producing this foliation was active. The northeast-trending foliation may be younger than the folds in the Texas Gulch formation.

The relation of igneous intrusion to deformation is not everywhere clear, partly because the relative ages of some of the rock masses have not been determined satisfactorily. Igneous intrusion and deformation may have been essentially contemporaneous, and hence, although the strike of foliation in two separate igneous masses may vary in trend, the time gap may have been short, and both igneous masses products of a single intrusive period. The diorite-gabbro complex west of the Indian Hills metavolcanics may be older than other mafic bodies, as the former is cut by the north-trending planar structures, and the others, in part, were emplaced along northeast-trending structures. The quartz diorite in the western part of the region appears to be younger than the north-trending foliation, and the granodiorite, granite, and gabbro in the eastern part of the Humboldt region have no obvious time relationship to either structural trend.

Faults undoubtedly are far more abundant than one would judge from a casual inspection of plate 1. The difficulty in recognizing faults is partly due to the lack of marker beds in the Iron King meta-andesite, Spud Mountain metabreccia, and Indian Hills metavolcanics, and partly to the difficulty of distinguishing faults from foliation. Considerable movement could have occurred along a relatively narrow zone in the foliation and never be recognized, as deformation was sufficiently strong to give all units and structural elements a general tendency toward parallelism. The relations of the folds to one another in the Texas Gulch formation strongly suggest considerable transport parallel to the planar structure. The Lonesome Valley fault is the only one exposed in the Humboldt region that is known to have post-Cambrian movement. It moved the gravels of Lonesome Valley against pre-Cambrian rocks in Pleistocene (?) time, but by analogy with the Verde fault, which bounds part of the Black Hills on the east, the Lonesome Valley fault may have moved in pre-Cambrian time also. A pre-Cambrian and a Tertiary period of movement for the Verde fault was established by detailed geologic mapping in the vicinity of the United Verde mine at Jerome (Reber, 1938, p. 51).

Folds large enough to duplicate formations were not proved. The outcrop pattern of the purple slate and the metarhyolite tuff units in the Texas Gulch formation suggests tight folds of small magnitude and the mapping of beds has proved folds in three different places. Lenticularity of the metarhyolite tuff, however, may in some places explain the outcrop pattern. If lenticularity exists, there is no assurance whether it results from deformation or from original deposition. Many folds similar in scale to those known and believed to exist in the Texas Gulch formation could be masked by the uniform lithology in the Iron King meta-andesite and the Spud Mountain metabreccia. One nearly isoclinal anticline was recognized in the Chaparral Gulch metavolcanics.

Pre-Cambrian structure

As in most regions of strong dynamic deformation, the Humboldt region shows a rough parallelism of all structural elements. With increasing intensity of deformation, the parallelism increases, until under extreme deformation the crests and troughs of folds are the only discordant elements; axial planes of folds, fold limbs, and foliation all are parallel; and locally the linear structures have a common rake. Although the Humboldt region has not reached the extreme condition, it shows a tendency toward parallelism of the structural elements within a given structural block. The structural pattern is complicated in the Spud Mountain metabreccia by the superposition of one structural trend upon another.

Bedding and foliation are commonly but not always parallel. In general bedding dips at a high angle and ranges in strike from north to northeast. The local variations are illustrated on plate 1. Bedding exerts control on the foliation chiefly as a plane of weakness along which slipping is more apt to occur, if the tendency is to break in that general direction. Ekkernkamp (1939, pp. 719-742) has shown in a series of controlled experiments in a pressure box that an earlier planar structure tends to control later planar structure that, in a homogeneous mass, would form in a different direction. In the Humboldt region there are numerous examples of foliation parallel to bedding and of foliation discordant to bedding.

The north-trending foliation is one of the oldest structural elements recognized in the Humboldt region. It is the dominant structure in the Indian Hills metavolcanics and in the diorite-gabbro complex and granite lying toward the west. Both the north-trending and later northeast-trending foliation are found in the Spud Mountain metabreccia, locally in the same outcrop. The meta-breccia also exhibits anomalous northwest-striking foliation near Spud Mountain. No counterpart for such a northwest-trending structure was observed elsewhere in the region, and its significance is unknown. The foliation in the Indian Hills metavolcanics,near the diorite dike bounding the Chaparral Gulch metavolcanics on the west, has a northeast strike. The change in strike suggests drag along the pre-Cambrian fault along which the diorite dike later penetrated. However, the change in strike may indicate a new foliation formed parallel to the fault. In either case, it demonstrates the younger age of the northeast structural trend in the Chaparral Gulch metavolcanics. In the Spud Mountain metabreccia the north-trending planar structure is dominant, whereas the northeast structural trend is prominent locally.

Northeast structural elements, which include foliation, joints, and faults, dominate in the Iron King meta-andesite and Chaparral Gulch metavolcanics, and are present in the Texas Gulch formation and Spud Mountain metabreccia. Foliation strikes generally N. 20°-30° E., except in the Chaparral Gulch metavolcanics where it is about

N. 45° E.; dips range from 70° W., through vertical, to 70° E. West dips are far more abundant. In the southern part of the Texas Gulch formation the foliation swings toward the northwest, but the lithologic units and the contact of the granodiorite (including the granite) on the west show the same change in strike. The cause of the change in strike is not clear, but perhaps it is related in some way to the configuration of the more massive granodiorite. In the Spud Mountain metabreccia the northeast planar structures are represented by fractures and local zones of foliation. The northeast-trending fractures are not abundant, but are well exposed in several places near the eastern contact in the southerly parts of the map. Movement on the fracture planes could not be established. Zones of northeast foliation are most common in the eastern part of the metabreccia and are represented by small zones of shear. Where well exposed they consist of zones of various widths of foliated rock that cleaves easily along the northeast foliation. These zones are separated by more massive metabreccia, which cleaves with difficulty along the north-trending foliation.

Lineation, manifest by mineral streaks in the foliation plane, plunges north in the Iron King meta-andesite and in the northern part of the Texas Gulch formation, but in the more southerly exposures of the Texas Gulch formation it plunges south. Lineation was not apparent in the Chaparral Gulch metavolcanics, but the anticline plunges north, at least in its southern part.

Tentatively the structural coordinates for the northeast structural elements can be defined for the area in which the lineation plunges northwards. Although there is considerable doubt whether the lineation marks the "a" or "b" direction, the north-plunging fold in the Chaparral Gulch metavolcanics suggests it is the "b" direction. The foliation plane defines the "a-b" plane and "b" plunges north at angles of 60° to 80°. The "c" direction is perpendicular to the plane of foliation.

No folds large enough to duplicate formations were proven in the Humboldt region, but three small folds are known in the Texas Gulch formation, and the outcrop patterns of the purple slate and the metarhyolite tuff strongly suggest others. A larger fold appears probable in the area cut by section C - C', plate 1, where both a metarhyolite and a purple slate unit bend around as if involved in the same fold. It is uncertain whether certain discontinuous outcrops are due to folds or to primary lenticularity, a common feature in volcanic sedimentary rocks. As bedding within some lithologic units has been obliterated almost entirely, the cause of an outcrop termination in them cannot be proved. Nevertheless plunging folds seem best to account for the map pattern of the largest units that stop abruptly. Two folds, both established by mapping metaconglomerate beds, lie in juxtaposition. The metaconglomerate bed could not be traced from one fold to the other. Furthermore both folds appear to be in the same sense, that is, both synclines or anticlines, judging by their direction of plunge and their relations to adjacent beds. Thus it seems probable that an intervening fold has been sheared or squeezed out. Close examination of the zone between the two folds did not reveal a fault, only a strong foliation. If folding dominates the outcrop pattern, then much movement along the well developed planar structures, such as this, is necessary to explain the relation of these folds, and some folds must plunge north and others south. If, however, the outcrop pattern is due to primary lenticularity, it may give no clue to the amount of transport along the planar structures.

The age relations of the folds and foliation in the Texas Gulch formation were not established with certainty; however, the writer believes that the folds may be the older. The regional strike of the lithologic units and of the fold axes, where known and inferred, are north; whereas the foliation, except near the granitic textured intrusive rocks, is dominantly N. 10°-15° E. The small area of Texas Gulch formation in the Humboldt region does not prove that the northeast foliation is dominant. However, if the regional exposures of the Texas Gulch formation for about 15 miles to the north are considered, the small angular discordance between the general trend of the foliation and that of the lithologic units becomes much more impressive. Thus it appears possible that the northeast foliation was superimposed on the north-trending folds.

The anticline in the Chaparral Gulch metavolcanics contains a metarhyolite tuff bed which is much thinner on the southeast limb than on the northwest limb; this thinning is believed to have resulted from shear, as foliation is very pronounced throughout the formation. The rocks in the crest of the fold are either much attenuated or, more probably, the plunge of the fold becomes nearly horizontal, for the metarhyolite tuff continues northward as a band from the point where both limbs of metarhyolite tuff meet in the crest of the fold. This fold appears to be related to the deformation producing the associated planar structures.

Though folds large enough to duplicate formations can not be proved, at least one is possibly present. The lithologic similarity of the metarhyolite tuff and conglomerate unit in the Iron King meta-andesite and of the metarhyolite tuff unit in the Texas Gulch formation is striking. Rocks are megascopically identical and the same rock types are represented in the conglomerate beds of both units. If the two units are in reality the same, the western meta-andesite tuff unit of the Iron King meta-andesite might be correlated with the western meta-andesite tuffs of the meta-andesite breccia unit in southerly exposures of the Texas Gulch formation. The Spud Mountain metabreccia would then be correlated with the eastern part of the meta-andesite breccia unit in the Texas Gulch formation. However, the two breccias are only similar in that both are composed predominantly of meta-andesite fragments with subordinate metarhyolite fragments.

The meta-andesite fragments in the Spud Mountain metabreccia are porphyritic whereas those in the Texas Gulch formation are nonporphyritic or are very inconspicuously porphyritic.

From here on it becomes difficult to match rock units on the two limbs of the hypothetical major fold. Several possibilities exist, all involving faults, for similar lithologic units are no longer symmetrically arranged on either side of a hypothetical fold axis. Presumably the fold axis would be somewhere in the central part of the Iron King meta-andesite, which contains hornblende-bearing mineral assemblages and intrusive rocks.

There are several strong arguments against the existence of such a fold. No lithologic units have been traced from one limb of the hypothetical fold to the other, and the only good lithologic match on both limbs is the metarhyolite tuff and conglomerate unit of the Iron King meta-andesite with the metarhyolite tuff unit of the Texas Gulch formation. Furthermore, all lineation in the Humboldt region and in the area to the north plunges steeply. This indicates that any folds would likewise plunge steeply. Therefore, if there has been no major faulting, beds should be traceable from one limb of the fold to the other. The similarity of the lithology of the two metarhyolitic units could have resulted from a repetition of similar conditions of deposition and of material deposited. With the present information, the fold exists only as a possibility and the map of the Humboldt region is drawn on the basis that a major fold does not exist.

In large part the symbols for minor folds in the Texas Gulch formation indicate small wrinkles in the foliation. They are more common along the Lonesome Valley fault than in any other area of equal size and probably resulted from movement along the fault. Others are too few and scattered to be interpreted.

In part, the intrusive history of the igneous rocks can be related to the stages of deformation represented by the foliation. The gabbro-diorite complex west of the metavolcanics of the Indian Hills is older than the north-trending foliation, whereas the mafic intrusive bodies in the central part of the Iron King meta-andesite appear to be essentially contemporaneous with the deformation producing the northeast structures, as they are controlled and cut by the northeast structures. Likewise the diorite and quartz diorite dikes and small irregular masses that bound the Chaparral Gulch metavolcanics are both controlled and cut by northeast structures. The granodiorite, granite, and gabbro in the eastern part of the Humboldt region have no obvious relationships to either the north- or northeast-trending structural elements. The structural features associated with the different igneous masses indicate that there are two generations of gabbro-diorite intrusives and that the quartz diorite was probably emplaced during development of the northeast structural elements.

Faults with movement in pre-Cambrian time are difficult to prove in the Humboldt region, possibly because with strong regional deformation the distinction between a fault and planar structures representing important lateral transport tends to disappear. The planar structures become "distributive faults." Two faults are indicated strongly but not proved by the dikes and irregular shaped intrusive masses that bound the Chaparral Gulch metavolcanics. Perhaps they only appear more like faults because they are planes marking structural discontinuities. The actual amount of movement on them may not have been any greater than on some zone within the Chaparral Gulch metavolcanics.

The faults or fractures localizing the Iron King ore deposit are postfoliation, as the foliation is intensely deformed next to them, and they are assumed to be pre-Cambrian because the Iron King ore deposit is analogous in many aspects to the pre-Cambrian massive sulfide deposit in the United Verde mine at Jerome, Arizona. Although there is no positive evidence for the postfoliation age of the shear zone localizing the Kit Carson and Silver Belt-McCabe veins, it is assumed to be the same age as the fracture system of the Iron King mine.

Paleozoic, Mesozoic and Cenozoic structure

The structural history since pre-Cambrian has been relatively simple. Although no lithologic units, which would indicate Paleozoic and Mesozoic deformation, occur in the Humboldt region, a section of Paleozoic rocks ranging from Cambrian to Permian occurs in the Black Hills, which bound the Humboldt region on the northeast. These Paleozoic rocks represent the most southerly extension of the Plateau region, which farther northward contains rocks of Mesozoic age also. Presumably the Humboldt region was covered at one time by the same Paleozoic section as is exposed in the Black Hills. Thus it would appear that the Paleozoic and Mesozoic history of the Humboldt region is essentially analogous to that of the southern Plateau region, which amounts to little more than simple uplift and subsidence at various times during these two eras. The Paleozoic rocks in the Black Hills have a homoclinal dip to the north of perhaps 5°. It is beyond the scope of this paper to review fully the Paleozoic and Mesozoic structural history of this region, but it does appear worthwhile to point out the absence of strong deformation during these eras.

Quaternary deformation in the Humboldt region occurred along the Lonesome Valley fault, which has moved basalt and the alluvium of Lonesome Valley against the pre-Cambrian rocks. The Lonesome Valley fault is a high-angle normal fault, dipping at about 75° or 80° westward. Although the basalt might be expected to furnish a datum plane by which the general stratigraphic displacement of the Lonesome

Valley fault could be determined, the altitude of the basalt on the footwall side of the fault at the time of faulting is not known, nor is it feasible to estimate its general position by extrapolation from other areas, as the basalt flowed out on an irregular erosional surface. In the Black Hills nearly horizontal basalt rests on gently tilted Paleozoic rocks and on pre-Cambrian rocks; extensive areas east and southeast of the Humboldt region are covered by basalt and related rocks which rest on an irregular surface carved from pre-Cambrian rocks. The difference in elevation between these two occurrences of basalt is roughly 2000 feet in about 12 miles, which may represent in a general way the relief in the district when the basalt was extruded.

HYDROTHERMAL ALTERATION, NOT ASSOCIATED WITH THE IRON KING ORE DEPOSIT

Hydrothermal alteration in zones not associated with the Iron King ore deposit has not been studied in any detail. Alteration that has at least bleached the rocks has occurred along the Kit Carson and McCabe-Silver Belt veins. The alteration is generally restricted to the sheared zones that comprise the veins. Bleaching also is common along the Lonesome Valley fault.

A wide alteration zone, characterized by quartz veins, magnetite, and pyrite, occurs within the eastern meta-andesite tuff unit of the Iron King meta-andesite (pl. 1). The zone appears to be metarhyolitic in composition, but it is not known whether the zone represents an altered rhyolite tuff or whether the apparent metarhyolitic composition is due to hydrothermal alteration. The rocks of this zone are predominantly light-colored on fresh fracture but reddish to black on weathered surfaces owing to stain by iron oxides and possible manganese oxide. Sericite is apparently a major constituent of the rock in contrast to the more chloritic rocks on either side. As quartz-sericite-pyrite is a common assemblage in hydrothermally altered rocks, the presence of more than average sericite in rocks in this vicinity suggests some secondary sericite. Quartz is abundant in veins ranging up to several feet in width. The veins in some places lie parallel to foliation, but in other places they transgress it, and many contain casts after pyrite and "boxwork" that suggest the former presence of chalcopyrite. Casts after pyrite are common in the rock itself. The light color of the rock might be due in part to bleaching by sulfuric acid derived from oxidation of pyrite. Much of the iron stain undoubtedly is due to iron oxide derived from pyrite.

The metarhyolite near the granite and granodiorite on the eastern margin of the region shows weak pyritization, and the meta-andesite breccia, quartz porphyry, and metarhyolite show textures that suggest albitization. Not enough specimens were collected to determine the extent of the suggested albitization, but the textures were recognized in specimens taken from localities separated by several miles. The metarhyolite, weakly pyritized over its entire extent, contains scattered euhedral pyrite crystals, which form iron-stained casts on weathered surfaces. Some secondary sericite also may be present, as sericite flakes penetrate quartz grains and rim idioblastic albite crystals. The albitization is indicated in the quartz porphyry and the meta-andesite breccia by pseudomicrographic textures between quartz and albite that are very much like those described by Gilluly (1933) from an albite granite near Sparta, Oregon. In the meta-andesite breccia and metarhyolite it is shown by accretion of albite on xenoblastic albite grains. The pseudomicrographic textures consist of various amounts of quartz and albite interpenetrating each other in irregular blebs and rods. In places the albite develops intricate branching forms, rosettes, and varied irregular patterns.

Within one quartz-albite pseudomicrographic grain the albite has the same optical orientation, possibly indicating that in three dimensions the albite blebs, rods, and branching forms are integrated. The replacement origin of the textures is suggested by the large variations in the relative abundance of quartz and albite from one albite-quartz grain to another, and commonly the albite appears to work out from microscopic fractures or from a central point to form the rosettes. However, the most convincing evidence for replacement origin is that the texture occurs both in a water-deposited meta-andesite breccia and in a quartz porphyry that is intrusive into the metabreccia. That these symplectic features occur only in rocks near the intrusive contact of coarse-grained granitic rocks, lends credence to a hydrothermal origin, as a logical source for the albitizing solutions is at hand. The growth of idioblastic albite crystals by accretion of clear albite on granoblastic (?) albite grains containing flakes of sericite and granules of epidote minerals is perhaps in itself not conclusive evidence of albitization; but when considered in combination with the symplectic quartz-albite texture, it is suggestive.

IRON KING ORE DEPOSIT

History and production

In 1901 Jaggar and Palache (1905) mapped the Bradshaw Mountains quadrangle and, although they did not mention the Iron King mine in the text of the folio, it is indicated on the geologic map by a symbol. In 1922 Lindgren (1926) studied the ore deposits of the Jerome and Bradshaw Mountains quadrangles and published some information on the history, production, and ore occurrence of the Iron King mine. According to Lindgren (1926, p. 128), the first production from the Iron King mine was in 1906 and 1907 from oxide ores. In 1907 it amounted to 1,253 ounces of gold, 35,491 ounces of silver, and 3,933 pounds of copper. Mining activity ceased soon thereafter, but was renewed during World War I by George Colovocoresses, who mined heavy sulfide for his Humboldt smelter. By 1922 several thousand tons of ore, averaging $8.00 per ton in gold and silver, had been shipped to the smelter.

The mine remained inactive from this period until 1936 when it was purchased at a tax sale by Fred Gibbs, Prescott, Arizona. In 1937 the Iron King Mining Co. purchased the mine and began development work on the lead-zinc veins. In 1938 a bulk flotation mill, 140 tons daily capacity, was put into operation and the following year converted to differential flotation and increased to 225 tons daily capacity. Subsequently the mill capacity was increased to about 500 tons daily capacity. The Shattuck Denn Mining Corp. purchased the physical assets of the Iron King Mining Co. in 1942 and has operated the mine since that time.

H. F. Mills (1941, 1947), General Manager of the Iron King mine, has described the history, ore occurrence, and mining; and H. R. Hendricks (1947) has reported on the milling. The mining and milling practices at the mine have been described further in two articles in the Mining World (1944a, 1944b).

Table 2.--Production of the Iron King Mine, Yavapai County, Arizona, in terms of metal content. (Based on figures supplied by the Iron King Branch, Shattuck Denn Mining Corporation)

	Metal mined tons	Gold oz.	Silver oz.	Lead tons	Zinc tons	Copper tons
1906-1938*	91,929	18,007	359,746	1,171	3,677	269
1939	70,227	9,911	272,604	936	2,927	175**
1940	65,812	9,239	266,497	945	3,610	164**
1941	69,159	9,720	331,746	1,160	3,808	173**
1942	91,213	12,180	443,952	1,910	4,965	228**
1943	75,309	8,672	317,127	1,762	5,570	203
1944	103,231	9,953	330,841	1,979	7,250	294
1945	120,211	13,164	438,369	2,705	8,742	267
1946	117,343	13,322	471,326	2,924	8,715	251
1947	122,368	15,297	533,642	3,097	8,463	206
Total	926,802	119,465	3,765,650	18,589	57,727	2,230

*some early production estimated
**approximate, but probably very close to actual production

The production of the Iron King mine from 1906 to 1947 is given in table 2. The average grade of all ore mined on the 400 and lower levels has been $7.00 per ton in gold and silver, 2.17 percent lead, and 6.80 percent zinc. In general, the dollar value of the gold was about twice that of the silver.

Mine water

The Iron King mine has produced consistently about 30 gallons of water per minute since 1937 or 1938. When new levels are drained through diamond drill holes, the amount of water pumped increases appreciably for a short time, but soon decreases to 30 gallons per minute. The mine water is slightly alkaline. Additional water for the mill is obtained from company-owned wells near Humboldt and pumped to the mine.

General features

The Iron King ore deposit consists of 12 massive sulfide veins arranged en echelon on the footwall of a hydrothermally altered zone which ranges from about 100 to 250 feet in width. Perhaps the most obvious feature of the Iron King ore deposit is its location in a zone of shearing. If other structural controls for the deposit exist, they were not recognized. The hydrothermal alteration occupies a zone of general shearing and the veins occupy restricted zones of more intense shearing along the footwall.

Quartz, ankerite, pyrite, and probably sericite, are the introduced minerals in the alteration zone, and quartz, ankerite, and pyrite are the recognized gangue minerals in the Iron King veins. During a period of intramineral deformation the early minerals were fractured and sheared. These structures were the ones that localized the ore minerals in the veins. Sphalerite, galena, tennantite, arsenopyrite, and chalcopyrite clearly belong to the ore-forming period of mineralization. A little quartz, pyrite, and ankerite also were deposited late, but it is not known whether they were introduced or were shifted from some other place in the deposit. A second period of hydrothermal sericite accompanied the ore-forming period of mineralization. This alteration concentrated chiefly around the north ends of the veins.

The veins have been cut by postmineral reverse faults. The maximum vertical displacement known on any of these faults is about 100 feet.

Hydrothermal alteration related to the Iron King ore deposit

The alteration zone associated with the Iron King ore deposit and those lying nearby are illustrated on plate 2. Three zones of alteration were recognized, one directly in contact with the deposit and two others, lying one on either side of the deposit. The central zone or hanging-wall alteration zone (so called because of its relation to the ore deposit) is the largest; it ranges from about 100 to 250 feet in width on the surface and extends for over 4000 feet along the strike. It was studied in most detail, as it is better exposed because of penetration at various levels by the underground openings of the mine.

Three subdivisions, whose contacts are more or less arbitrarily placed, were mapped in the study of the surface exposures of the alteration zones. These subdivisions are illustrated on plate 2. Adjacent to the veins the alteration is most intense, and the rock contains a greater concentration of quartz, pyrite, and ankerite. Southward this subdivision grades into a zone in which quartz, ankerite, and pyrite are not as abundant but are still common, particularly in zones alternating with others in which the original character (meta-andesite tuff) of the host rock is apparent. The third subdivision comprises the south end (not shown on plate 2) of the central zone and all of the eastern and western zones. Sericite appears to be the dominant platy mineral, pyrite is very rare, and secondary quartz and ankerite are not megascopically abundant except in local patches.

It is difficult to separate the early introduced minerals formed by so-called hydrothermal alteration from those that were deposited during the ore-forming period of mineralization, as both are products of one more or less continuous period of mineralization.

The designation of the early phase of mineralization as hydrothermal alteration is arbitrary, but useful as a designation to distinguish, in the discussion that follows, between the early widespread introduction of minerals and the concentration of the ore-forming minerals in the Iron King vein system. Quartz, ankerite, pyrite, and probably sericite are the early minerals deposited throughout the hanging-wall alteration zone and probably were concentrated in the fracture system which was the predecessor of the ore veins. These minerals are known to have been deposited early because they were brecciated and sheared intensely before the ore-forming minerals were introduced. Thus it appears that the ore deposit formed during deformation. These early minerals continued to be deposited during the formation of ore, for quartz, pyrite, ankerite, and sericite appear to have been deposited late as well as early. However, it is difficult to say whether the late quartz, pyrite, and ankerite represent the introduction of actual new material or reworking of early-stage minerals.

All or part of the assemblage quartz-pyrite-carbonate-sericite is common in the altered zones of ore deposits. Schwartz (1947, p. 322) in a paper summarizing the hydrothermal alteration of porphyry deposits gives quartz-sericite-pyrite as a distinct type of alteration in the copper deposits at Inspiration-Miami, Ray, Sacramento Hill (Bisbee), and Castle Dome (in part) all in Arizona and at Bingham (in part) in Utah.

The occurrences of the introduced minerals forming the hydrothermal alteration zone are somewhat varied. Veinlets and irregular patches or lenses of quartz, pyrite, and ankerite are abundant. The veinlets, generally lying parallel to the pronounced planar structure but commonly transecting it, consist of all three components, of various combinations of two, or of only one. Quartz occurs as a general silicification as well as in veinlets in the altered rocks. In thin-section the distributed quartz is in microscopic granoblastic-cataclastic grains. Because of the intense deformation subsequent to the introduction of the early hydrothermal minerals, it is impossible to distinguish introduced quartz, unless it is in veinlets, from quartz originally present in the metamorphic rocks, even though quartz is perhaps several times as abundant in the hydrothermally altered rocks. Irregular-shaped quartz grains commonly contain inclusions of apatite which may indicate a secondary origin for this quartz. Apatite is more abundant in the alteration zone than in the adjacent meta-andesite tuffs; in two sections it composed by estimate between 5 and 10 percent of the rock.

Pyrite occurs as individual crystals disseminated in the altered rocks and in veinlets associated with other alteration minerals. A series of individual pyrite crystals arranged along a given "s-plane" is a common feature of the central alteration zone as exposed in the underground openings of the Iron King mine. Ankerite, probably because of its high solubility, appears to accompany both early and late stages of mineralization and to vein the last stage sulfide minerals. Sericite has two occurrences, (1) in small amounts widespread in the alteration zone where it is associated with quartz, pyrite, and ankerite, and (2) in local concentrations along the veins and particularly at the north ends of the veins. The sericite in the second occurrence is believed to be younger than the sericite disseminated in the alteration zone, as the sericite associated with the ore veins and occurs in veinlets that locally cut the ore-forming sulfide minerals. However, distinction between early and late hydrothermal sericite could not be made in all thin-sections, for in many sections sericite lies with its basal section parallel to planar structure whether it formed before, during, or after the period of deformation that is the basis for distinguishing the early hydrothermal and the later ore-forming period of mineralization.

It is noteworthy that the hydrothermally altered rocks rich in sericite but relatively poor in pyrite and quartz, such as in the eastern and western alteration zones and the southern extension of the hanging-wall alteration zone, are more or less peripheral to the Iron King veins. It is not known whether or not this is significant or purely fortuitous.

Zones in which pyrite, quartz, and ankerite are more abundant alternate with others in which these minerals are distributed sparsely, and these successions persist to the walls of the veins, where commonly both pass into sericitic schist. Chlorite is abundant in the zones of sparse hydrothermal minerals, but decreases with increase of the hydrothermal minerals. Crosscutting microscopic veinlets of chlorite, seen in a few thin-sections, attest the mobility of chlorite during the alteration period.

For a short distance south of the ore shoots, the Iron King veins are composed essentially of quartz, pyrite, and ankerite, and these minerals are the host for the ore minerals. Hence it appears that during the pre-ore stage well-developed veins were formed in the Iron King fracture system while the sheared zone to the west was being sporadically mineralized along planar structures and short discontinuous fractures. Deformation during the mineralization period fractured and granulated these early minerals, as cataclastic and mortar textures were recognized in every specimen examined microscopically. Comb quartz in the pressure shadows of deformed pyrite is a common product of the intramineralization deformation.

The outcrops of the alteration zones are generally white to cream-colored and of the central zone are stained by iron oxide that marks the former presence of pyrite. The white color was attributed at first to abundant sericite, but as rocks below the water table are generally green, and thin-sections from surface rocks contain abundant colorless chlorite as well as sericite, it is concluded that the white color is due in part to bleaching action of sulfuric acid formed by oxidation of pyrite. Lasky (1936, p. 64) has described similar bleaching along many of the veins in the Bayard area, Central Mining District, New Mexico. In the outcrops of the central zone of hydrothermal alteration casts after pyrite are common, and carbonate has been largely dissolved by sulfuric acid.

Within the part of the alteration zones illustrated on plate 2, small partly altered relicts of meta-andesite tuff are common and indicate the host rock for the ore deposit. Toward the south, owing to the decreasing amounts of pyrite, ankerite, and quartz, the rock adjacent to the veins grades into fine-grained, closely foliated, light-colored rock that appears to be sericitic.

Thin-sections from outcrops of the hydrothermal alteration zone contain a small amount of a probably clay mineral. The clay (?) mineral has a negative 2E of about 35° and a birefringence near 0.010. The indices of refraction could not be determined from the thin-sections and not enough was found for determination in oil mounts of powdered rocks. The clay(?) mineral forms irregularly shaped microscopic masses composed of fibers or narrow plates commonly oriented at right angles to the long dimension of the grain and to the foliation in the rock. The growth of the fibers or plates perpendicular to the foliation indicates an authigenetic origin later than the last period of deformation. The clay(?) mineral was not recognized in rocks from underground and accordingly is believed to be a weathering product. As the mineral probably formed in an acid environment produced by oxidization of pyrite, a clay mineral from the kaolinite group would be most likely. Bateman (1927, p. 583) has described kaolinization due to oxidation of sulfides in the sericitic alteration zone near massive pyrite deposits of Rio Tinto, Spain.

Sericite is difficult to place in the history of the deposit, for it is erratically distributed in the hanging-wall alteration zone, and its habit is not diagnostic of age relative to deformation. Underground most concentrations of sericite are closely related to the veins and especially to the quartz-rich north ends of the veins, although some exceptions occur. Commonly a narrow sericite septum separates the north-end quartz from the remainder of the vein, and unreplaced septa of wallrock in the veins are generally sericitic. Generally, masses of sericite schist at the north end of a vein narrow southward along the vein walls and grade into well-foliated meta-andesite tuff mineralized by more or less quartz, pyrite, and ankerite. Commonly the sericitic or partly sericitic selvage of a vein is only a few inches wide. Some sericite is erratically distributed throughout the hanging-wall alteration zone, but it is probably less abundant than the chlorite and does not form concentrations, such as those at the north ends of the veins.

Sericite, within the veins, formed late in the mineralogical sequence of the Iron King deposit. Within the veins, it is in microscopic veinlets that cut quartz, pyrite, ankerite, and sphalerite. Individual flakes lie in the cleavage planes in ankerite and in the pressure shadows of pyrite grains transverse to the planar structures in the vein filling. The same age is suggested for sericite, immediately adjacent to the veins, which occurs in small slender needles lying as much as 45° off the foliation direction and for microscopic veinlets composed of undeformed plates of sericite that cut rocks in which all other minerals are deformed. As stated elsewhere, the north ends of the veins are separated from the hanging-wall alteration zone and terminate in meta-andesite tuff. Hence, the sericite schist that envelops the north ends of the veins is commonly independent of the quartz-pyrite-ankerite alteration in the hanging-wall zone; this suggests to the writer a more or less distinct period of introduction for this sericite. Where this sericitic rock grades into chloritic rock in the footwall, the sericite is in veinlets or stringers perfectly concordant to foliation, and resembles the associated chlorite in habit. This suggests that sericite is mimetic after chlorite or a planar structure. Such sericite has the habit and distribution that are expected if it had been formed earlier and was later deformed. Thus, although some sericite associated with the veins formed late, and some of it after the ore minerals, no reliable textural criterion was found for dating the sericite in the hanging-wall alteration zone; on the bases of distribution and association, however, some sericite, chiefly that in the hanging-wall alteration zone, is believed to have formed with the early quartz, pyrite, and ankerite.

The association of large masses of sericite schist with the north ends of the quartz veins, though not invariable is too common to be fortuitous. As some quartz "noses" do not have the sericite schist envelope, the solutions that deposited the quartz were not responsible for the sericite, for then the association would be invariant. The C vein, well-exposed in the back of a drift on the 1100 level, perhaps affords an explanation (fig. 2). Sericite schist can be seen to "flow" around the quartz "nose", join, and extend down the drift and into the wall as a sericite vein. The sericite is clearly limited to a zone of shear, and the shear appears to be postquartz. A quartz "nose" in the I vein on the 900 level, void of the sericitic envelope, ends in a sharp point in massive meta-andesite tuff. In other places where sericite is abundant, small sericite veinlets in the quartz were observed, and the narrow septa of sericite that commonly separate the quartz "nose" from the remainder of the vein have the appearance of veinlets. Hence, the sericite probably developed after the quartz and was controlled by shear zones cutting the meta-andesite tuff near the quartz "noses". Deformation of this period also may have permitted introduction of the ore minerals.

The sericitic zones lying to the east and the west of the altered zone associated with the Iron King ore deposit are probably alteration zones rather than original metarhyolite units, as they appear to be controlled by zones of more intense deformation rather than bedding. The rock has a much more pronounced planar structure than the adjacent meta-andesite tuffs, probably because the more intense shear localized the alteration. The most-altered rocks consist chiefly of very fine-grained sericite, quartz, and carbonate with here and there an albite grain and small amounts of residual chlorite. These rocks grade into others that contain abundant chlorite and also sericite, and are interpreted as representing intermediate stages of alteration. Some irregularly shaped masses of residual meta-andesite tuff occur within the alteration zones. A thin-section of the rock from the western zone shows a quartz vein that has been sheared into two augen. Each shows mortar structure and the two are connected by a microscopic veinlet of mylonitic quartz. However, though no age differences based on fabric could be established between chlorite and sericite, an age difference might not be apparent if the sericite was mimetic after chlorite or foliation. The proximity to the Iron King ore deposit and the similarity of mineralogy and more pronounced foliation between the hanging-wall alteration zone and those on either side seem sufficient to relate these bounding alteration zones to the mineralization which formed the Iron King deposit.

Sulfide veins

DISTRIBUTION AND ATTITUDE

The massive sulfide veins in the Iron King deposit are exposed on a surface area about 2500 feet by 250 feet (pl. 2). Subsurface openings on the productive veins extend to a depth of about 1140 feet below the collar of No. 6 shaft, but the surface gives the most complete exposure of all the veins in any horizontal section. The productive veins comprise the group lying along the footwall of the alteration zone north of the 1250 N. coordinate, plate 2. They are essentially strike veins, as they deviate from both bedding and foliation by only a few degrees. The part of the report dealing with the Iron King ore deposit is concerned chiefly with these veins and the ore shoots within them.

The ore deposit consists of 12 veins arranged en echelon. The individual veins strike about N. 22° E. and dip 71° NW., and in plan view each succeeding vein on the west extends farther to the north than its next easterly neighbor. In section the veins maintain a similar en echelon arrangement. In any particular vertical section each vein to the west extends to a higher altitude than its eastern neighbor. All the veins plunge northward, and the plunge for individual veins is commonly constant, the angle of plunge from vein to vein varying between 55° and 60°. The vein width is commonly constant for individual veins over short distances but ranges between 1 and 14 feet for different veins; the lengths are measurable in hundreds of feet. From southeast to northwest the veins are designated as follows, X, Y, P, A, B, C, D, E, F, G, H, and I, plates 4, 5, and 6.

The en echelon arrangement occurs only with the veins in the eastern part of the hanging-wall alteration zone, and it is rigidly maintained by the north ends of the veins but not by the southern terminations.

All workings on the veins above the 600 level were inaccessible for study, except some service drifts and crosscuts so scattered that they aided little in interpreting the lower levels. The 600 level is accessible from 100 feet north of No. 6 shaft to 100 feet south of No. 2 shaft. This part was mapped but is not illustrated in the report. The 700, 800, 900, 1000, and 1100 levels, however, were completely accessible and are illustrated by plates 4 and 5.

The nonproductive veins are erratically distributed through the hanging-wall alteration zone. In general little is known about these veins below the surface. Most of them are shorter than the ore veins and they are probably just as discontinuous with depth. The Copper vein (opened by Copper shaft) is the widest and most continuous, but its continuity between the north and south segments is uncertain (pl. 2). Diamond drilling from underground openings below the 700 level penetrated vein material similar to the Copper vein and in the same position relative to the ore deposit and the alteration zone. Not enough is known to estimate its continuity, but most if not all diamond drill-holes through the alteration zone encountered copper minerals near the hanging wall of the alteration zone. All the non-productive veins, as well as can be seen from surface exposures, parallel the foliation in the altered wallrocks.

VEIN STRUCTURES

The Iron King veins were formed by replacement within en echelon fractures that controlled the spatial relationships, widths, lengths and to some extent the internal structures of the veins. Whether these fractures or faults were formed simultaneously with the shear zone represented by the hanging-wall alteration zone, or whether they were formed somewhat later is not entirely clear. An age difference might be interpreted from the small angular discordance between the individual veins and the shear zone. However, the early gangue minerals in the veins, although more concentrated, are the same as those sporadically distributed throughout the hanging-wall alteration zone, indicating that at the time of earliest mineralization both structures were present. This, of course, does not preclude the possibility of two periods of fracture prior to mineralization. The significance of the slight angular discordance between the veins and the shear zone is most difficult to interpret, especially as the rock affected was strongly anisotropic owing to the foliation. The veins mark zones of more intense shearing, and hence indicate zones in which stresses were stronger. Perhaps here the resolved stresses at an angle to foliation were strong enough to produce breaking across the foliation, whereas in the hanging-wall zone the weaker stress at an angle to foliation resulted in movement chiefly along the pre-existing folia. The close spacing of the en echelon fractures that control the veins and the relatively wide spacing of similar points on the veins, such as the north ends, suggest that the fractures or faults result from a shear couple. The plunge of the lineation in the walls of the veins and the corresponding plunge of the north ends of the veins indicate that the plunge of the direction of relative movement was steep, but until the lineation can be established as either the "a" or "b" structural coordinate, it cannot be said whether the principal axis of transport plunged to the south or to the north. The ore deposit at the Eustis mine, Quebec, demonstrates a somewhat similar en echelon arrangement of massive sulfide lenses. Stevenson (1937, p. 348) attributes the localizing structure to the action of two opposite and tangential forces. The localization of massive sulfide bodies in fractured and brecciated zones has been described by Finlayson (1910, p. 405) for the Huelva deposit, Rio Tinto district, Spain; by Graton (1909, pp. 92-99) for the pyritic deposits in Shasta County, California; and by Capps and Johnson (1915, p. 92) for the massive sulfide deposit in the Ellamar district, Alaska. Hanson (1920) studied a number of pyritic massive sulfide deposits in Canada to determine the relationship of the form and structure of the ore bodies to the enclosing rock. After considering the Mandy mine, Manitoba; Northpines mine, Ontario; Flin Flon, Manitoba-Saskatchewan; and the Eustis mine, Quebec, he concluded that the sulfide resulted from replacement in "zones of more intense shearing and brecciation." The Sullivan mine, Canada, appears to be an exception, for according to Swanson and Gunning (1945, p. 651) the deposit is controlled by a stratigraphic zone. However, the tourmaline and cassiterite in the deposit suggest a greater depth of origin than many other massive sulfide deposits.

A second period of movement is indicated clearly by strong fracturing and brecciation of the early introduced minerals. This later movement controlled the distribution of the second-period minerals that produced the ore shoots in the veins. The distribution of the second-stage minerals suggests that the later movement, in the veins at least, took place along fracture zones that extended from the footwall to the hanging wall of the veins.

The I vein, although designated as one vein, actually consists of at least three individual echelons; the most northerly is not exposed completely by underground openings. This explains in part the greater length of the I vein. The individual echelons of the I vein, marked I_1, I_2, and I_3 on plates 4 and 5, show all the characteristics of individual veins, such as quartz "noses," consistency of plunge, and characteristic mineral distribution with the component echelons. In all other parts of the deposit, adjacent veins lie to the west or east of the strike extension of the reference vein, but in the I vein the partings between echelons are narrower, and there is a slight tendency for the succeeding echelon to bend until it lies along the strike extension of the previous one. Hence these three echelons have been regarded as one vein.

The P vein is unusual, for it plunges much less steeply and is the only vein whose limits are exposed completely within the zone mined. The plunge, 25° N., of the P vein is at least 25° flatter than any other, so that the vein occupies an intermediate position between the Y and A veins. The vein apexes above the 400 level and bottoms a short distance below the 700 level, figure 1. On the 400 level it is almost a part of the Y vein; however, in depth it diverges to the north of the Y vein, and on the 700 level is separated by 250 feet from the north ends of the Y vein and lies next to, and about as far north as, the A vein, figure 1.

Individual veins that have much of their strike length exposed to observation appear to have a tendency toward a gentle curvature that is convex eastward. The X vein on the surface illustrates this feature (pl. 2). Its strike varies 5° between its southern and northern limits. This feature is not limited to the Iron King ore deposit; both the Kit Carson and Silver Belt-McCabe veins are curved in a similar manner (pl. 1). Furthermore, the strikes of beds at the north and south ends, respectively, of the Silver Belt-McCabe vein do not deviate appreciably from each other, but the vein changes in strike from N. 65° E. to N. 27° E. The common curvature of the veins in the area mapped suggests a common origin; if the curvature is primary, it suggests that the Silver Belt-McCabe, Kit Carson, and the Iron King vein-forming structures are essentially the same age.

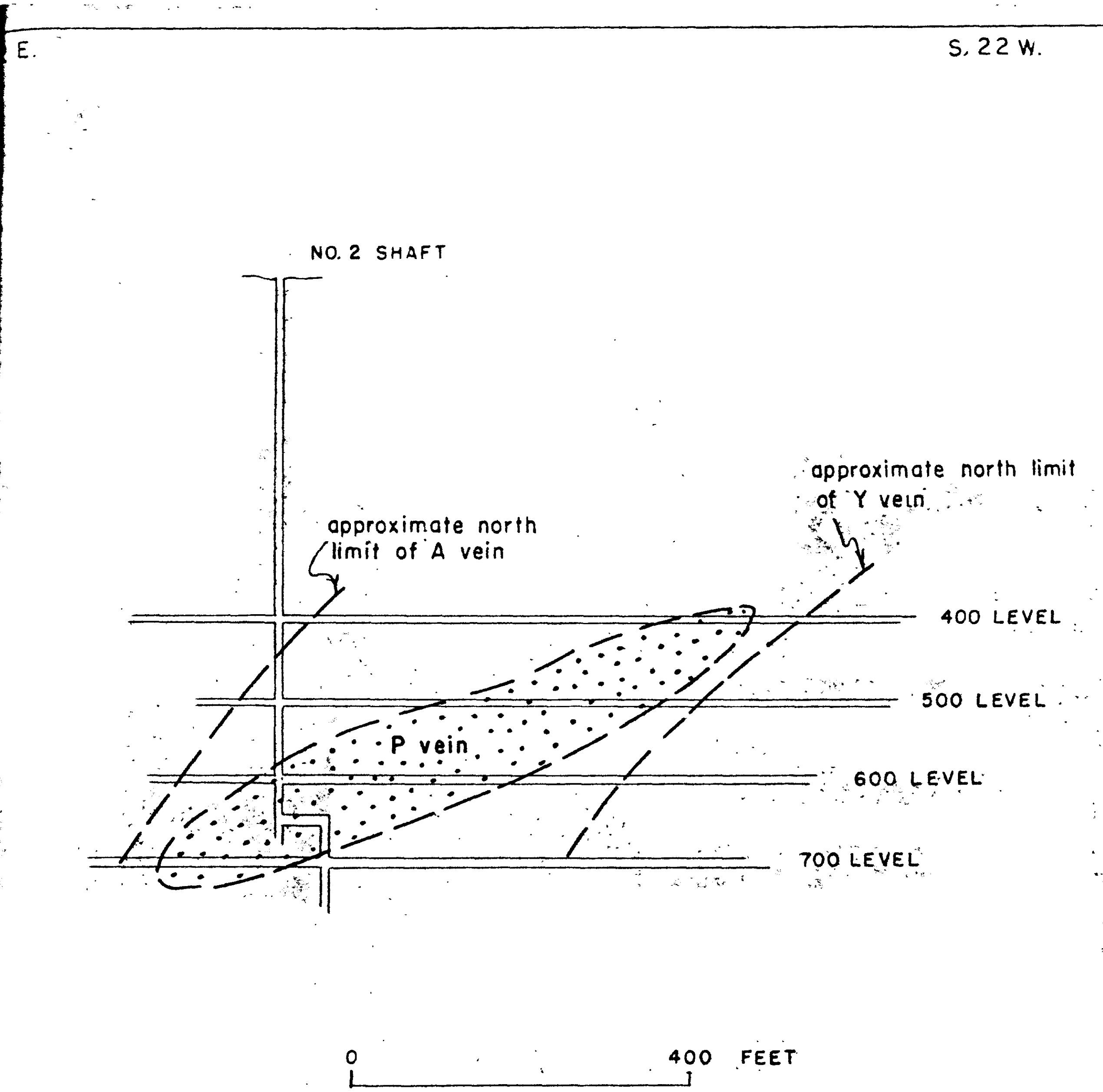


Figure I. Generalized longitudinal projection of the P vein

Variations from an ideal en echelon pattern occur in some of the individual veins. On the 900 and 700 levels the X vein consists of two separated segments but on the 800 level only one vein exists (pls. 4 and 5). The veins must join and split between the 700 and 900 levels. The B and C veins, lying between the A and D veins, represent subsidiary structures, as they do not maintain the en echelon pattern (the B vein was omitted from plates 4 and 5 because of lack of space). The A vein extends as far to the north as the C vein and considerably farther than the B vein. The B and C veins probably should be considered parallel veins to A, and not be included in the en echelon pattern.

In general, the veins and the schist septa separating them are consistent in width from the surface to the 1100 level, and with rare exceptions, such as the local junction of the north ends of the E and F veins, adjacent veins do not join. The septum between the E and F veins is commonly not over 2 feet wide, and that separating the H vein from the G and I veins is most commonly not over 5 feet wide. In places, as on the 1100 level, the veins have been moved together by postmineral faulting, but these occurrences are not considered here. Variations in the widths of the C, H, F, and G veins are known. Between the 200 and 600 levels the C vein, ranging in width from 5 to 10 feet, produced some ore, but it is narrow and unproductive on the lower levels. The H vein ranged from 10 to 15 feet in width on the 300 and 400 levels and was 10 feet wide on the

500 level, but it narrowed to about 2 feet between the 500 and 700 levels. The G vein increased in width below the 600 level, and the increase is roughly commensurate with the decrease in the width of the H vein. A general reverse relationship between the widths of the two veins appears to exist. According to Mills (1941, p. 57), the F vein changed into a wide, low-grade, extremely siliceous body between the 400 and 500 levels, but it narrowed to its former width before reaching the 600 level.

So far as known all the veins except the P are continuous throughout the depth of the deposit, and the contacts between massive sulfide veins and wallrocks are very sharp. These features and the consistency in vein widths suggest that the original fractures were sharply defined and distinct.

One of the most striking features of the veins is the abrupt change from massive sulfide with no megascopic vestige of host rock to wallrocks with almost no vein minerals, at least on the footwall side. In many places a knife blade will cover the contact. Commonly a narrow band of gouge separates the vein material from the rock.

For one or two feet from the veins the foliation in the wallrock appears to parallel the veins. As the veins are locally broken by postmineral faults, both the marginal gouge and the parallelism of veins and foliation seems logically explained by this postvein deformation.

The ore minerals are not uniformly distributed throughout the veins, for in places massive sulfide veins in which no wallrock exists contimue for 100 feet or more south of the economic limits of mining. A short distance south of the ore shoots the vein structure becomes generally weaker and replacement of rock material less complete. Plate 3, therefore, does not give an accurate picture of either the distribution of ore or the relative degree of replacement.

The north ends of the veins are exposed best by the underground openings; additional information on their shape and size was obtained from diamond-drill records. The north end of the C vein, 1100 level, is exposed completely in the back of the drift (fig. 2). Other informative exposures are the D vein, 700 level, and the E, F, and I veins, 900 level, plates 4 and 5 and figure 3. The northern terminations vary considerably in pattern. Commonly the vein swells to perhaps twice its normal width; the E and F veins were thereby joined on the 800 and 900 levels. The D vein, 900 and 800 levels, and the G vein, 700 level, also widen. In contrast, some of the individual echelons within the I vein end by pinching out (fig. 3).

Fracture zones continue northward from the ends of some of the veins, as is illustrated by the C vein, 1100 level, figure 2. The fracture zones extend only short distances, as is shown by diamond drilling. Generally they are marked by abundant hydrothermal sericite and lesser amounts of quartz and ankerite; the alteration follows the fracture zone as a veinlike projection from the irregularly

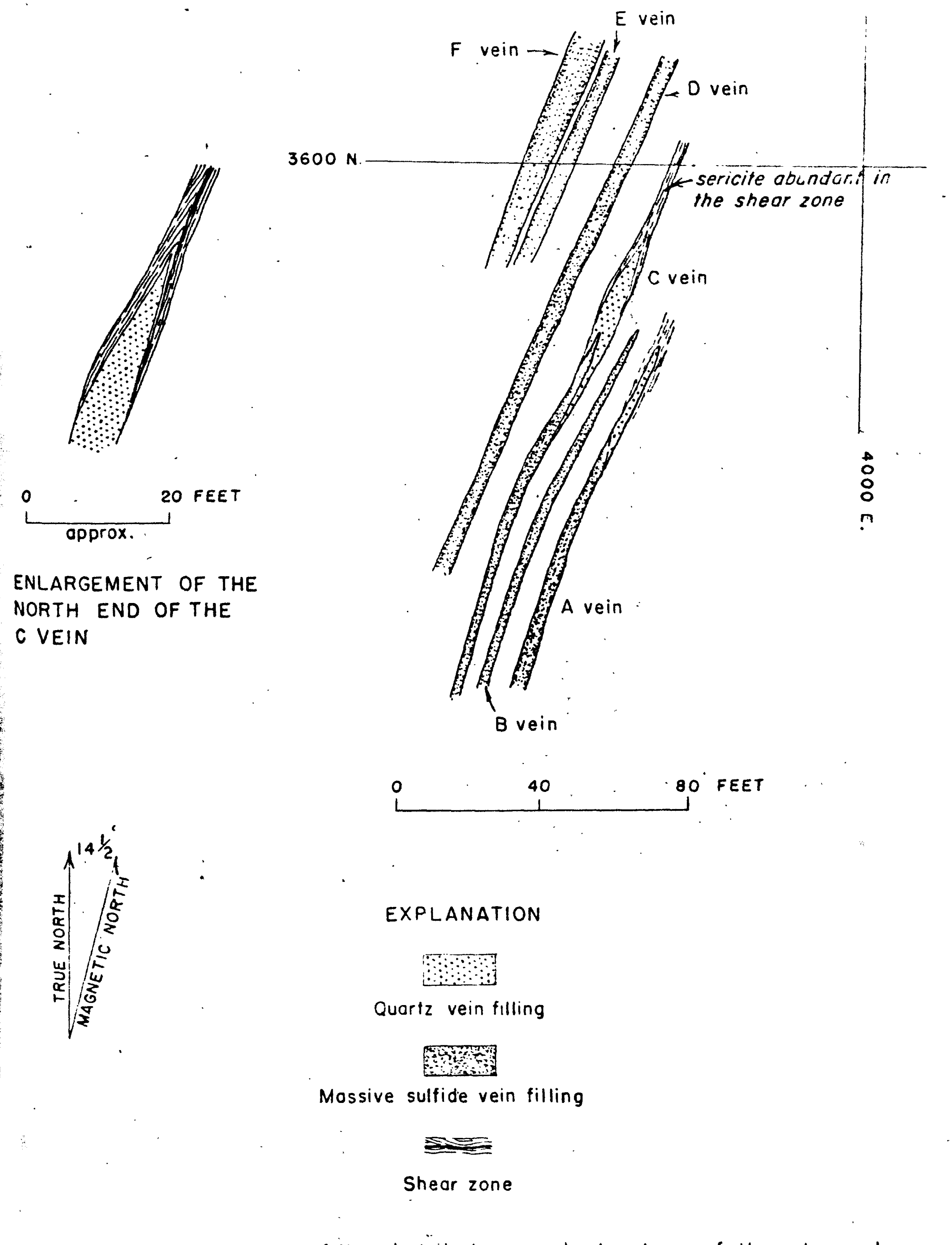


Figure 2. Plan view of the distribution and structure of the sheared and sericitized zone surrounding the north end of the C vein, 1100 level

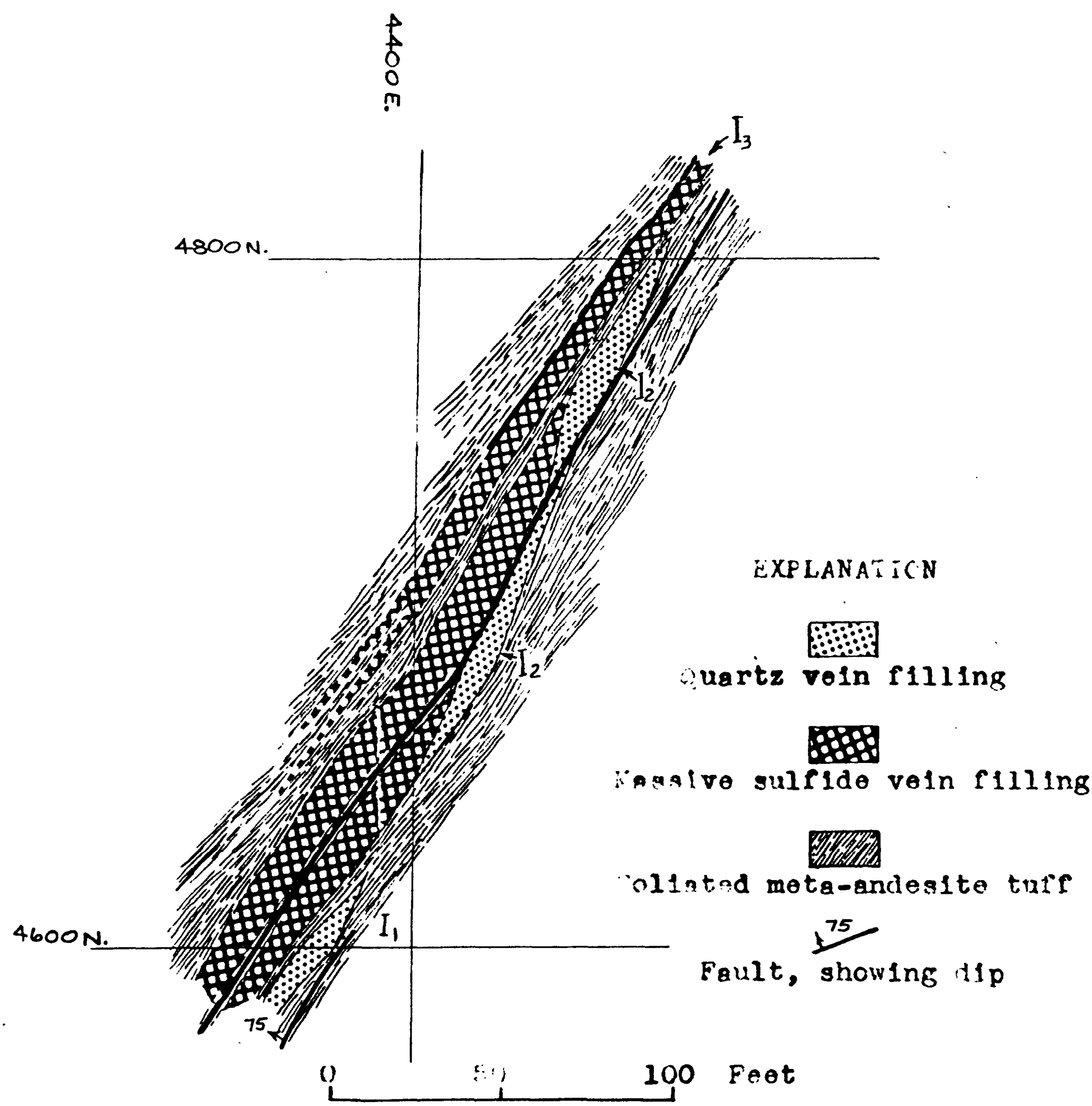


Figure 3. Plan view of the relationship between I_1, I_2, and I_3 segments of the I vein, 900 level

shaped, hydrothermally altered mass surrounding the northern sections of the veins. Wherever observed, the fracture zones cut and generally disturbed the foliation, leaving little doubt as to their post-foliation age.

The structures in the rocks that existed in the space now occupied by the massive sulfide is thought to be reflected to some extent by the banding in the sulfide. To this extent the massive sulfide gives clues to the character of the original localizing structures. The irregularities consist of (1) continuous, wavy bands, (2) discontinuous, nonparallel banding, and (3) irregular fracture networks. Regular banding also occurs, and all gradations between the regular and irregular exist, but generally not in the same vein or the same general area. In the ore zones some banding is due to the deposition of sphalerite in fractures, and replacement of early minerals by sphalerite along microscopic fractures, but in other places, such as in nonproductive veins, it results from the alternation of bands relatively rich in pyrite and in quartz, ankerite or both. This alternation was observed in narrow veins whose banding conforms to the foliation in the wallrocks and is as regular and perfectly developed as the foliation. Where only one stage of mineralization was recognized, the banding in the veins probably reflects variations in relative rates of deposition of the different minerals. The most prominent banding, that in the ore shoots, is partly due to the concentration of the late ore-forming minerals along narrow bands in the early vein filling. It appears clear that the combination of planar structures and variation in the relative rates of deposition of the different minerals resulted in the banding.

Banding is common in most deposits of massive sulfide, but it is by no means always present. It has been attributed to pseudomorphism of various older structures, such as bedding, fractures, and foliation. Massive sulfide deposits are characteristically fine-grained, thereby favoring preservation of small features by pseudomorphism.

VEIN FILLING

The general similarity of the mineralogy of massive sulfide deposits is most striking. Some differences and variations do occur, but variations in relative abundance of the different minerals is to be expected from one deposit to another, and variations in minor amounts of rare minerals does not obscure the general similarity. In general the massive sulfide deposits contain pyrite, sphalerite, chalcopyrite, and generally galena; in many, galena occurs only in minor amounts. In table 3 the mineral assemblage of the Iron King ore deposit is compared with that of six other massive sulfide deposits.

At the Iron King mine, the vein filling consists generally of fine-grained massive sulfides and massive quartz in sharp contact with the wallrocks. The massive sulfides vary in color from pale yellow to nearly black, depending on the ratio of pyrite to sphalerite and carbonate. The massive quartz is gray, white, and greenish gray. Fine banding produced by differences in the relative amounts of pyrite, sphalerite, or, gangue is present almost universally in the massive sulfide ores and is less marked in the nonproductive parts of the veins. Here and there on all levels narrow schist partings, most commonly under 6 inches in width, occur within the veins.

The principal sulfide vein minerals are pyrite, arsenopyrite, sphalerite, galena, and tennantite, and the nonsulfide minerals are ankerite, quartz, sericite, and a little residual chlorite. Gold and silver constitute the rare metals. The gold is free, and according

Table 3.—

	Iron King, Arizona	Sullivan mine, Canada (Swanson and Gunning, 1945)	Huelva, Rio Tinto district, Spain (Bateman, 1927)	Shasta County, California (Graton, 1909)	United Verde deposit, Ariz. (Reber, 1938)	Rammelsberg, Germany (Lindgren & Irving, 1911)	Mandy mine Manitoba (Hanson, 1920)
sulfide minerals	pyrite	pyrite	pyrite	pyrite	pyrite	sphalerite	pyrite
	arsenopyrite	arsenopyrite	arsenopyrite	chalcopyrite	marmatite	chalcopyrite	arsenopyrite
	sphalerite	pyrrhotite	sphalerite	sphalerite	chalcopyrite	galena	sphalerite
	galena	marmatite	galena	galena	bornite	pyrite	chalcopyrite
	chalcopyrite	galena	tetrahedrite	bornite	chalcocite	arsenopyrite	galena
	tennantite	chalcopyrite	enargite		tennantite		
		boulangerite	luzonite				
		magnetite	famatinite				
		cassiterite	chalcostibite				
			whitneyite			(listed in	
			umangite			order of	
			hauchecornite			abundance)	
			ullmanite				
			berthierite(?)				
Gangue minerals and hydrothermal alteration products	quartz	chlorite	sericite	quartz	chlorite	barite	sericite
	ankerite	albite		calcite	quartz		carbonates
	sericite	tourmaline		barite	specularite		quartz
	apatite (?)				dolomite		chlorite
							rutile

to Mills (1947) is carried largely in pyrite; the silver is believed to be in the tennantite. Pyrite is the dominant sulfide mineral and in places constitutes by estimate as much as 75 percent of the vein. Quartz and ankerite are the dominant nonsulfide minerals, and locally either may be most abundant. The north ends of the veins are almost exclusively quartz; whereas in the central section ankerite is commonly more abundant.

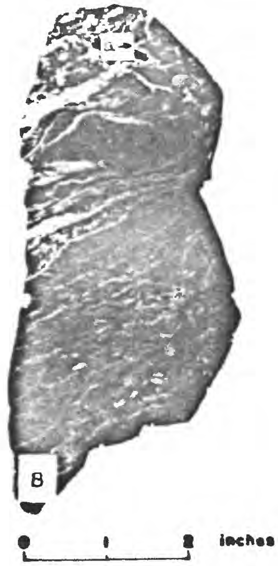
The vein filling is very fine grained. The upper limit of grain size is about 1.5 mm., and the lower limit is less than 10 microns. Most of the grains are estimated to range in diameter between 100 and 300 microns. Arsenopyrite occurs in grains that attain a diameter of 1.5 mm., and intergrowths of galena and tennantite occur in grains estimated at 1 mm. in long dimension. Some pyrite crystals, especially in the southern sections of the veins, attain diameters of about 300 to 400 microns. Masses of pyrite are much larger, but they are aggregates of xenomorphic pyrite crystals, as shown by etching with nitric acid. Sphalerite, galena, chalcopyrite, and some tennantite, commonly occur as smaller grains interstitial to pyrite and arsenopyrite.

The crystal habits range from idiomorphic to xenomorphic granular. Pyrite commonly has idiomorphic outlines against every other mineral. In areas of massive pyrite, however, mutual interference produces aggregates of xenomorphic crystals. Arsenopyrite exhibits crystal outline against galena, ankerite, and sphalerite, but not against pyrite or other arsenopyrite. Crystal outlines of sphalerite, galena, and tennantite were not observed, but in places they replace ankerite, retaining the rhombohedral cleavage angle in the outline of the grain.

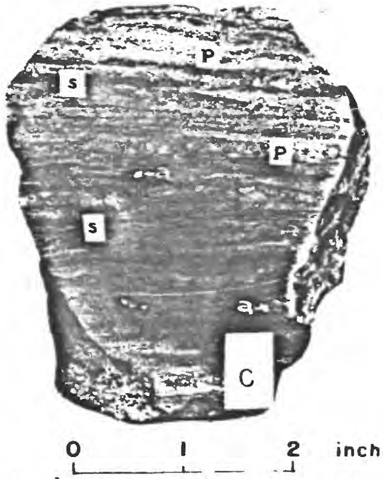
Banding, widely distributed throughout all the veins, is the most characteristic feature of the vein material (pl. 7). Individual bands range in width from about 1 mm. to 3 or 4 cm. Continuity in the length of individual bands is more difficult to establish, in part because of poor conditions underground for such observations. However, lengths of several feet parallel to both strike and dip were observed in stopes. Color variations resulting from the differences in the relative amounts of the various minerals produce the megascopic banding. Bands relatively rich in pyrite and sphalerite, respectively, are the most abundant and produce the most marked color banding, but local concentrations of arsenopyrite, quartz, and ankerite also contribute to the banded structure.

The distribution of the minerals within the veins is consistent in the larger veins on all levels but is not uniform. The north ends of all the veins consist almost entirely of greenish to gray or white quartz that appears almost chalcedonic. Here and there along the footwall of the veins lenticular bodies of similar quartz occur. Some of them are connected to the quartz at the north ends of the veins, but others apparently are independent bodies. The marginal quartz mass occurring within the I_1 segment of the I vein is connected to the quartz nose on the 900 level but is apparently independent on the 800 level (pls. 4 and 5). The level maps show other quartz masses

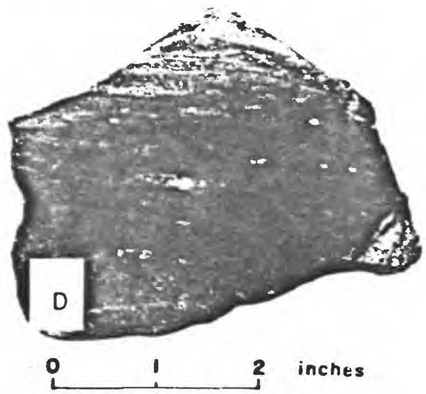
A. BANDED MASSIVE SULFIDE FROM A VEIN, 900 LEVEL
The banding is produced by zones rich in quartz (q) alternating with zones rich in pyrite (p). Massive sulfide, containing coarse granular pyrite and widely spaced bands, is characteristic of the south ends of the veins and is generally not ore. Ankerite knots (a)



B. MASSIVE SULFIDE FROM I VEIN, 900 LEVEL
Ramifying veinlets of late pyrite. In the lower part of the specimen, the small pyrite veinlets cut sphalerite-rich massive sulfide. Ankerite veinlet (a)



C. TYPICAL BANDED ORE, I VEIN, 900 LEVEL
Bands rich in sphalerite (s) alternating with bands rich in pyrite (p). The fine grain size is typical of good ore. Ankerite knots (a)



D. BANDED ORE, G VEIN, 1000 LEVEL
The fine grained massive sulfide in the top part of the specimen is typical ore and consists of bands rich in sphalerite (dark) alternating with bands rich in pyrite (light). The more granular massive sulfide in the lower part of the specimen is chiefly pyrite (light) and quartz-ankerite (dark). Note the angular discordance between banding in the two types of massive sulfide.

of this type, and the veins contain several other masses that are too small to indicate at the scale used for the illustrations. The greenish to gray or white quartz contains disseminated idiomorphic pyrite crystals and is cut by ramifying sulfide veinlets and by massive white quartz (fig. 4). In places, the quartz at the north end of the veins is rich in gold and silver, as on the G vein, 600 level. Other bodies, as indicated on figures 5, 6, and 7, contain average or less than average amounts of gold and silver. No megascopic differences were observed between some barren quartz and ore quartz; however, greenish quartz is valueless, according to John Kellogg, the mine geologist. The transition from quartz to the massive sulfide is sharp and regular. Plates 4 and 5 and figure 3 illustrate the pattern of the transition and in every vein the pattern is similar. The quartz-sulfide vein contact strikes more northerly, cuts the vein at an acute angle, and transgresses from footwall to hanging wall. The angle between the contact and the vein is varied, ranging from a few degrees to 30°. The G vein, 900 level, and D vein, 800 level, illustrate the two extremes.

South of the quartz at the north end of the veins, the chief variation in mineral content consists of an inverse relationship between amounts of pyrite and sphalerite. Assay data illustrate these changes for the D and G veins, 600 to 1100 levels, and for the F vein, 500 to 1100 levels (figs. 5, 6, and 7). The assay data are accurate, as samples are cut at very close intervals on all productive

N. 65 W. S. 65 E.

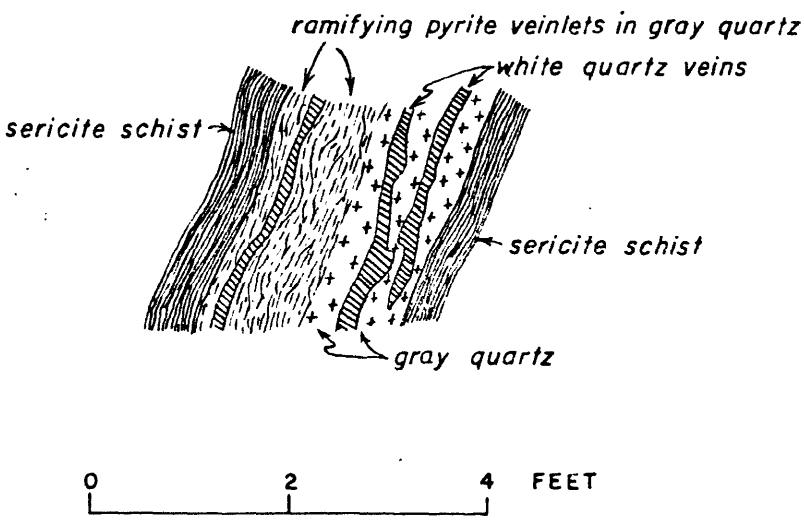


Figure 4. Sketch of cross section of X vein, 700 level, showing white quartz veins and ramifying pyrite veinlets in gray quartz vein filling

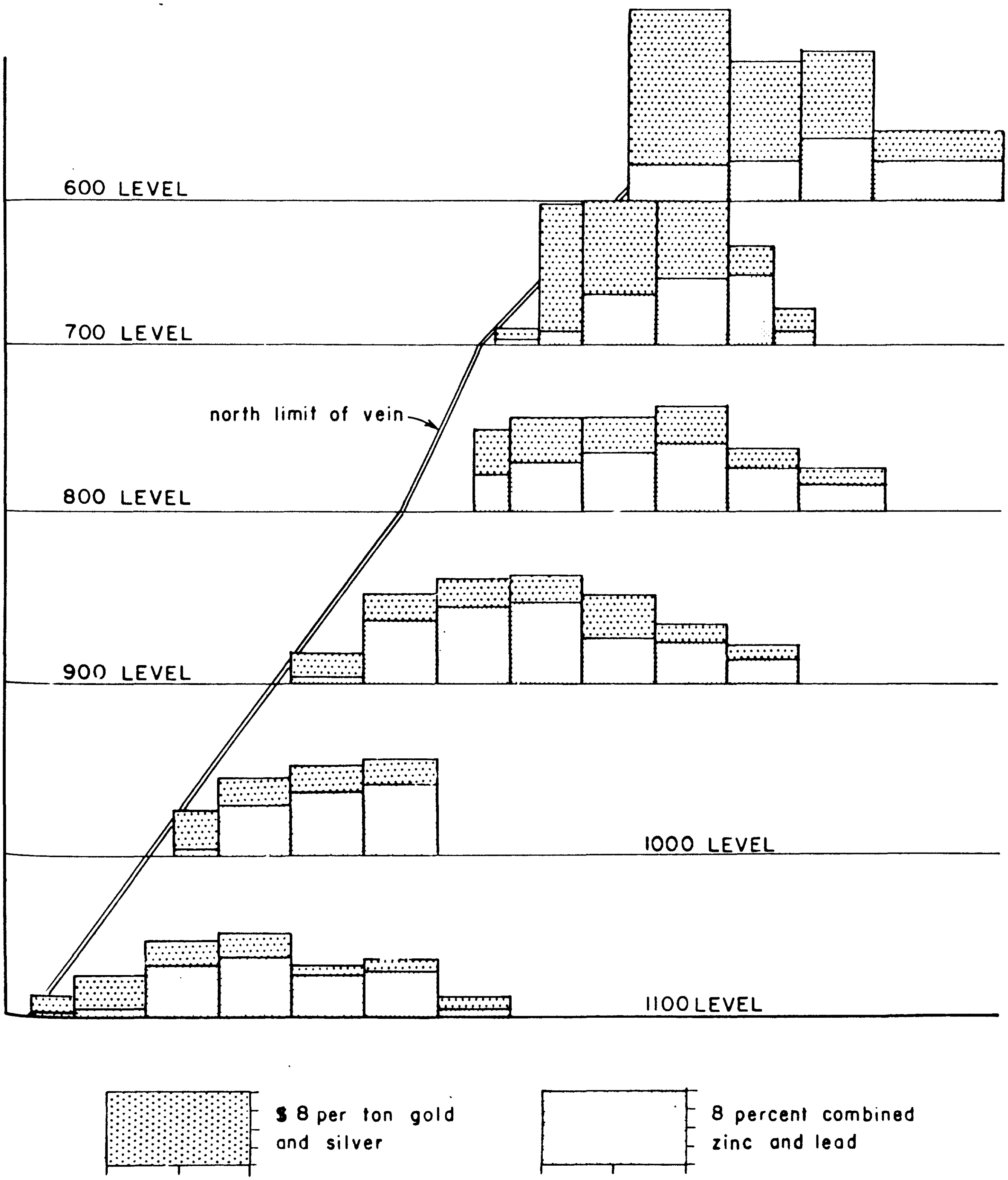


Figure 5

DISTRIBUTION AND GRADE OF THE BASE AND PRECIOUS METALS, D VEIN, IRON KING MINE

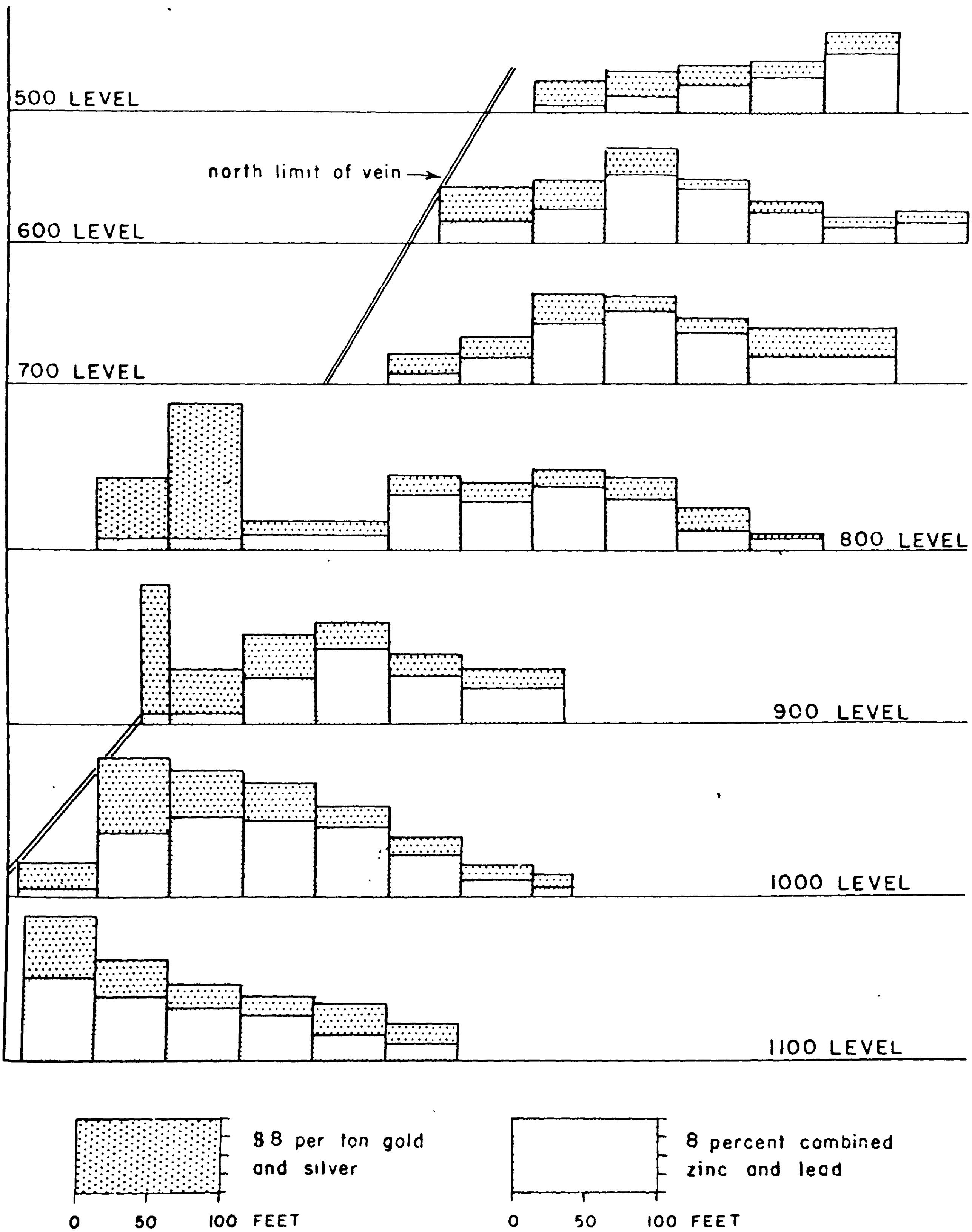


Figure 6

DISTRIBUTION AND GRADE OF THE BASE AND PRECIOUS METALS, F VEIN, IRON KING MINE

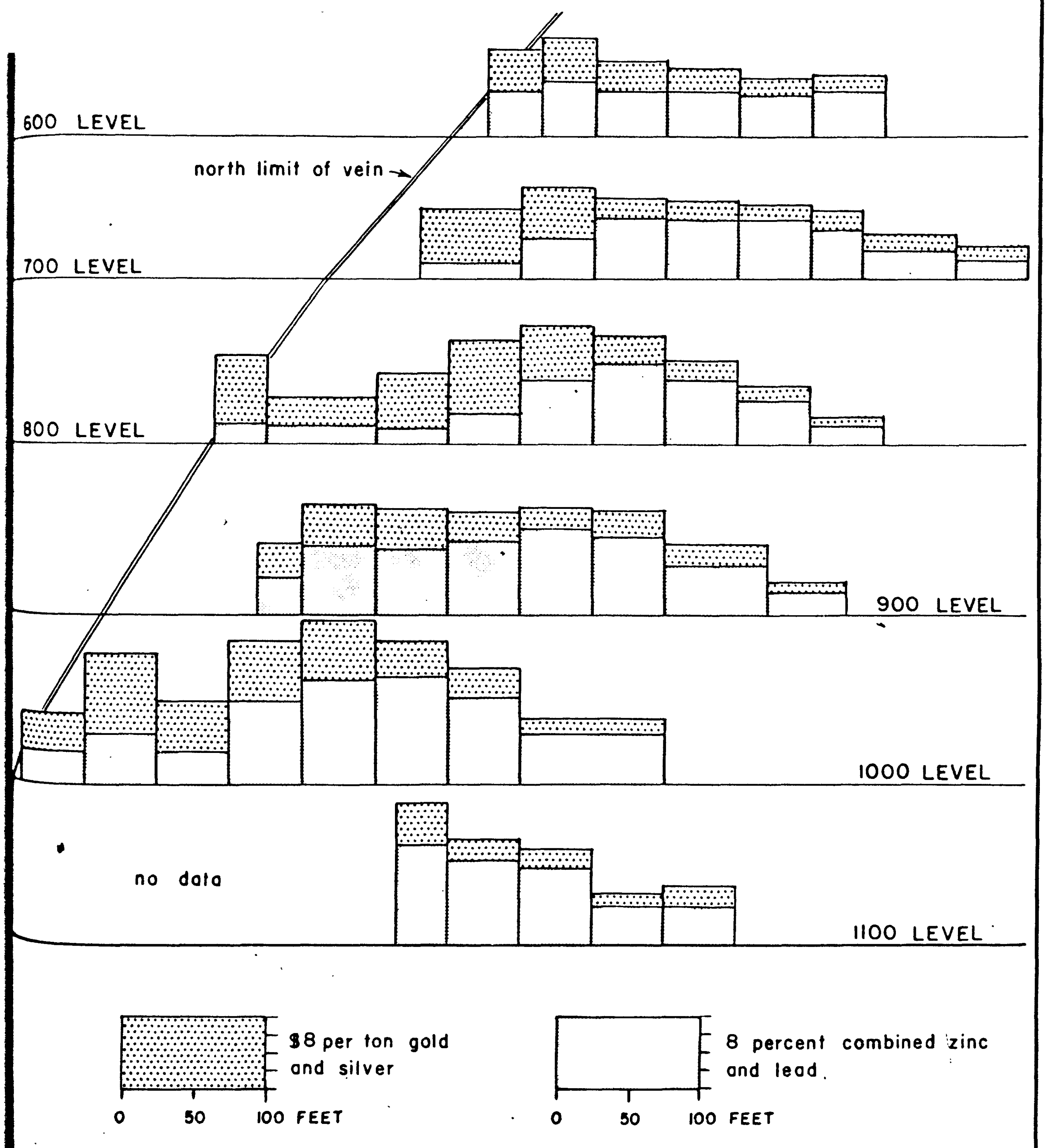


Figure 7

DISTRIBUTION AND GRADE OF THE BASE AND PRECIOUS METALS, G VEIN, IRON KING MINE veins, and individual samples are broken at significant changes in vein structure or composition. In general the dollar value of gold is consistent enough as twice that of silver to permit combining them for simplicity of illustration. Lead and zinc are combined in the diagrams, and but little information is lost, as lead usually is distributed uniformly throughout the minable limits of a vein. On the D and F veins lead averages between 1.50 and 1.75 percent, and on the G vein about 2.50 percent. The ratio of lead to zinc, therefore, is much higher for the section of the vein just south of the massive quartz and to a lesser extent near the southern limit of mining (figs. 5, 6 and 7). The variations shown in the graphs are due chiefly to the sphalerite content, which increases rather sharply from the massive quartz southward to a maximum amount and then decreases gradually. The south limit of mining is everywhere an "assay wall." However, zones relatively high in sphalerite start at a point on the footwall and cut across to the hanging wall at an acute angle to the vein, duplicating the pattern of the contact between the massive sulfide and quartz at the northern end of the vein. The assay graphs show plainly that any line of equal grade will parallel generally the north plunge of the north ends of the veins and that a spatial relationship exists within the vein between the rare and base metals. In every vein the gold plus silver maximum occurs north of the lead plus zinc, but not so far north that no overlap exists between the two. The dollar value of the gold and silver is high at the lead-zinc maximum, but is appreciably less than the maximum dollar value. This feature of the deposit is consistent.

In the veins, the quartz masses, including both the quartz noses at the north end of the veins and the less common lenticular masses along the footwalls, are commonly separated from the massive sulfide by thin partings or septa of sericite schist. The most common type of parting, usually chlorite schist, enters the vein from the hanging wall, and after continuing for distances up to several hundred feet, terminates. In places the last few feet are thin chloritic films only a few millimeters thick. The north I vein is divided into several parts by thick partings that cross the vein (fig. 3). Where this occurs, the individual segments have all the characteristics of an independent vein, such as internal zoning and a quartz mass at the northern termination. In a few places narrow partings enter the vein from the footwall, migrate well into the vein, and then back into the footwall metatuffs. The veins contain numerous narrow partings, ranging in length from a few inches to as much as 100 feet, that in plan view are entirely within the vein. In three dimensions many of them, especially the larger ones, undoubtedly are connected to the wallrock.

PARAGENESIS OF THE VEIN MINERALS

The paragenesis of minerals determined microscopically is held by the writer to be most significant when interpreted in relation to the local and regional geology established by geologic mapping. The chief value of microscopic study alone is mineral identification.

The following geological background is necessary, therefore, to understand the relations observed through the microscope. The veins constitute a massive-sulfide replacement of a foliated meta-andesite tuff in well-defined fractures. The amount of displacement, if any, of meta-andesite tuff by massive sulfide is not known, as only evidence for replacement was observed. The fractures, which localized the veins, and the massive sulfide veins are younger than the regional metamorphism. Intramineralization deformation was strong and consisted of brecciation and shearing of the early vein material. Postmineral deformation is limited to a few faults whose maximum vertical displacement is of the order of magnitude of 100 feet and whose exposures indicate well-defined breaks rather than widespread brecciation.

The regional mapping does not disclose any pervasive postmineral deformation, although local postmineral faults exist. The period of shear or fracturing resulting in the Iron King, Kit Carson, McCabe-Silver Belt, and other smaller veins in the district, is interpreted as the last stage in the more or less continuous deformation producing the metamorphic terrain and structures in the Iron King district.

The similarity of the pattern of mineral distribution in each vein, as described in the section on the vein filling, further suggests a common and simple history.

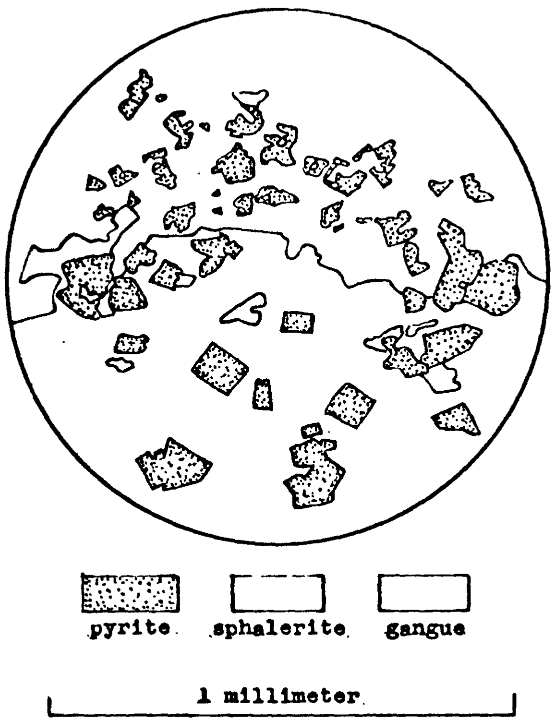
Pyrite, arsenopyrite, sphalerite, galena, tennantite, and chalcopyrite are the primary sulfide minerals recognized in the microscopic study of the ores. Quartz, ankerite, stringers of wallrock, and traces of residual chlorite (?) and late sericite are the nonsulfide constituents of the veins. In the ore shoots, ramifying veinlets of various mixtures of sphalerite, galena, tennantite, chalcopyrite, and arsenopyrite have pyrite-carbonate-quartz vein material as a host, and where the former minerals are not abundant, the later constitute the principal vein material. This is the commonest and most significant association observed. Pyrite-carbonate-quartz material constituted the initial vein filling; the later period of brecciation of the early vein minerals was followed by the introduction of the sphalerite, arsenopyrite, galena, tennantite, and chalcopyrite in one general period of mineralization. Pyrite, quartz, and ankerite may have accompanied this later stage, as they also occur in cross-cutting relations. From the geologic mapping of the veins and the microscopic study of the ores, the minerals of the second period appear to be essentially contemporaneous with one another.

Significant age relations of the minerals of the later stage for the entire deposit were not established, chiefly because apparent age relations could be determined in less than 1 percent, by estimate, of the pairs in mutual contact and some of these relations contradicted others. Schouten (1934)produced replacement artificially in the laboratory and showed some of the possible sources of error in the determination of age relations; selective replacement is the chief cause of error. If selective replacement is extensive, age determinations would not be significant. Widespread and consistent occurrence of veined and pseudomorphed minerals is diagnostic evidence for age relations under most conditions, but such consistency was not observed among these vein minerals.

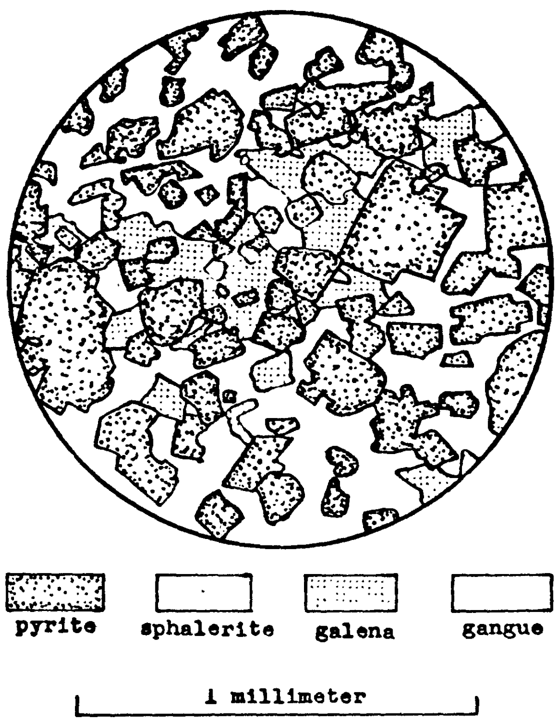
The following more detailed descriptions of individual mineral species are included for the common associations and occurrences of the minerals. The inferred age relations are stated as a matter of record.

Two types of sphalerite occur, the ordinary or rosin variety and marmatite. Marmatite is by far the most abundant, constituting over 90 percent of the sphalerite. An analysis of the marmatite by the American Cyanamid Company for the Iron King mine gave zinc 63.5 percent, ferrous iron 3.2 percent, and Sulfide 33.3 percent, which corresponds to 95 percent zinc sulfide and 5 percent iron sulfide. Marmatite is the earlier mineral and in places is veined by the rosin variety. The marmatite occurs chiefly as streaks or bands of relatively pure material which contribute greatly to the banded structure of the veins. In part, these bands certainly represent replacement features, as residual pyrite grains are dispersed irregularly through them in various stages of replacement, and on either side of the veinlet idiomorphic pyrite occurs. Plate 8A illustrates the character of the pyrite oh either side of the contact of a band rich in sphalerite. The pyrite in the upper part of the field is replaced partly by sphalerite, whereas that below the contact is unmodified. Commonly marmatite is interstitial to pyrite that shows little or no modification of the crystal outlines (pl. 8B). Such a relation could mean either (1) simultaneous deposition of pyrite and marmatite, (2) or selective replacement of early quartz-carbonate by marmatite, or (3) replacement of sphalerite by pyrite. Under the microscope sphalerite was observed as veinlets in quartz, ankerite, chalcopyrite, arsenopyrite, and galena. It is veined by galena and is included as small grains in chalcopyrite and very commonly in pyrite. Idiomorphic arsenopyrite in a matrix of sphalerite was observed; locally the arsenopyrite outline is undisturbed, but elsewhere it has been modified by the sphalerite. In places sphalerite forms pseudomorphs after ankerite preserving the rhombohedral angle. Parts of the vein that are rich in sphalerite are rich also in tennantite, galena, and arsenopyrite.

Rosin sphalerite occurs in late crosscutting veinlets associated with clear quartz; to a lesser extent it occurs with ankerite and tennantite and as disseminated crystals whose age relations are obscure. Several nests of rosin sphalerite were found on comb quartz that filled a late crosscutting fracture. A few crosscutting microscopic veinlets contain both marmatite and rosin sphalerite. In none



A. Complete replacement of gangue and partial replacement of pyrite by sphalerite, I vein, 700 level.



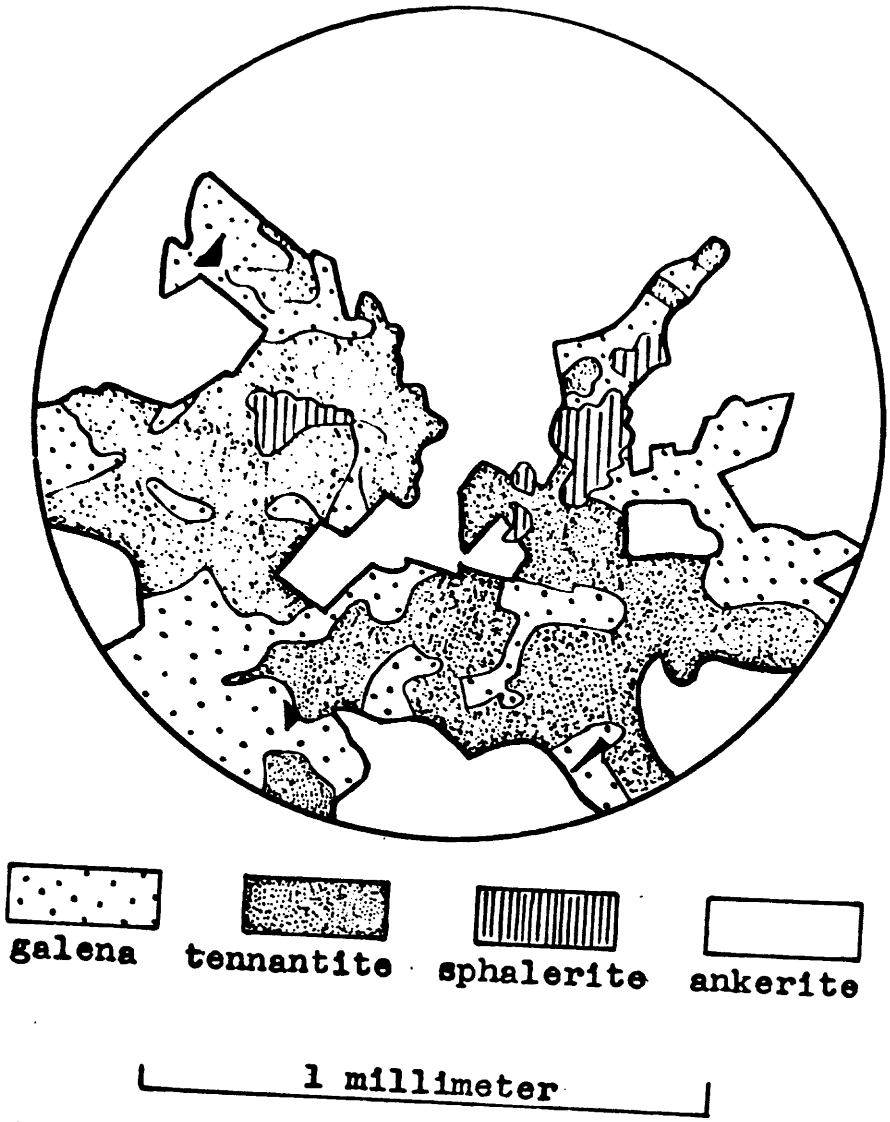
B. Sphalerite interstitial to pyrite that shows no modification of crystal forms, H vein, 900 level.

of them were the mutual age relations discernible, but the general occurrence of the rosin sphalerite strongly suggests a later age.

Galena rarely constitutes more than 4 percent of the vein material, yet it is present in every polished specimen from productive veins examined. Galena and tennantite are associated very closely (pl. 9). Galena, tennantite, and chalcopyrite also form a common association. No evidence was found for any age difference between the galena and tennantite. Galena is interstitial to pyrite and arsenopyrite. It veins marmatite and arsenopyrite and is veined by marmatite. Galena, associated with rosin sphalerite and pyrite, was observed perched on comb quartz crystals in an open fracture. Most of the galena and associated tennantite are in pyrite-free zones of quartz and carbonate (pl. 9) that form part of the megascopic banded vein structure and augen (less than 1 cm. in length) in the vein. The galena and tennantite occur in the quartz-ankerite bands as irregular grains and as ramifying microscopic veinlets that in general parallel the banding in the vein. In the augen they most commonly occur as large grains at the ends, and where more abundant tend to rim the augen completely. In a few places galena replaced pyrite, as indicated by small irregular residuals of pyrite enclosed in galena. Had the pyrite been younger, it most certainly would be in idiomorphic crystals, as the power of crystallization of pyrite is many times that of galena.

Chalcopyrite occurs only in amounts less than 1 percent in the productive veins. It is limited chiefly to small, irregular, inde-

PLATE 9



Relationships of galena and tennantite, G vein, 1000 level.

pendent grains; small masses associated with tennantite crystals; and microscopic blebs in sphalerite. Chalcopyrite veins pyrite, arsenopyrite, and quartz-carbonate, and is veined by sphalerite.

Arsenopyrite is abundant in the veins, particularly in the ore. Commonly it has good crystal outlines, chiefly diamond-shaped in section, against all minerals except pyrite and other arsenopyrite. Arsenopyrite in veins associated with sphalerite, tennantite, galena, and chalcopyrite cuts through pyrite-rich vein material and contributes to the banded structure of the veins. In several polished sections arsenopyrite is more abundant than pyrite, and a few of the larger arsenopyrite crystals contain small, irregular unreplaced residuals of pyrite.

The distribution and occurrence of tennantite is similar to that of galena. No mineral that has silver as an essential part of its composition was found in the vein; the silver, therefore, by analogy with deposits elsewhere, is probably in solution in the galena and tennantite. Assays of the mill concentrates reveal that silver is more closely associated with copper than with lead. Fluctuations in copper content of concentrates are always accompanied by a proportionate change in silver. Hence most of the silver is probably in the tennantite, although microchemical ammonium bichromate tests for silver were unsuccessful. However, Short (1940, p. 201) was unable to obtain ammonium bichromate microtests for silver in tennantite that assayed 1 percent Ag.

Although gold was not observed during the microscopic study of the ores, sufficient data are known from metallurgical tests and assays to summarize its occurrence. The gold is free and occurs in galena, sphalerite, and pyrite. Pyrite carries most of the gold, chiefly because pyrite is more abundant. Gold is distributed throughout the veins, as indicated on figures 5, 6, and 7, but the ratio of precious to base metals is higher for the quartz at the north ends of the veins than for the rest of the veins. Higher local concentrations of precious metals also occur in the quartz noses. These relations strongly suggest that the gold is in the pyrite. The precious metals, in a similar manner to the base metals, gradually decrease in amount southward.

The carbonate is probably ankerite. The omega index of material occurring as knots and as interstitial filling in the vein is 1.710. Material from a small quartz-carbonate-chlorite veinlet cutting the meta-andesite tuff south of the Iron King mine has an omega index of 1.725. All the carbonate reacts slowly to dilute acids with effervescence and all tested gave strong microchemical tests for iron. From index alone ankerite and ferrodolomite cannot be distinguished from magnesite or magnesite with partial replacement of magnesium by iron or manganese. But, according to Winchell (1933), neither magnesite nor siderite react with cold dilute acid, whereas dolomite, ankerite, and ferrodolomite may. On the basis of index and reaction with dilute acid, a member of the dolomite-ankerite-ferrodolomite series would seem most probable. This fact is further substantiated by the occurrence of the carbonate, much of which was deposited contemporaneously with pyrite. Under such conditions, ions of both magnesium and iron must have been plentiful. Manganese oxide stain was not observed on the weathered carbonate, indicating that manganese does not enter into the composition. Oxidation releases the iron in the carbonate, coloring the carbonate a dark red.

The occurrence, index of refraction, microchemical tests, and slow effervescence with dilute acid suggest the carbonate is ankerite, corresponding to 65 percent dolomite (Ca Mg C_2O_6) and 35 percent ferrodolomite (Ca Fe C_2O_6). The carbonate with the index of 1.725 contains equal amounts of dolomite and ferrodolomite molecules, according to Winchell's (1933, p. 74) charts.

Quartz and ankerite are both associated and independent of each other. Some polished sections contain a predominance of one or the other. In general the northern sections of the veins contain more quartz, and the central parts are richer in carbonate. Small veinlets of quartz, ankerite, or both, here and there cut pyritic vein material. Some of them may carry also rosin sphalerite, galena, or tennantite. In one polished section a quartz-tennantite-galena veinlet cuts ankerite.

POSTMINERAL STRUCTURAL FEATURES

Postmineral structural features consist of faults, joints, and probably slip cleavage. The larger faults that have offset the veins are all reverse faults. Those that dip steeper than the vein produce an overlap of the vein; those that dip less steeply produce a gap. Other faults of similar attitude but whose direction of relative displacement is not known also occur in the mine, especially in the northern parts of the 800 and 900 levels. A nearly flat reverse fault occurs on the 900 level.

All of the high-angle reverse faults are nearly parallel in strike and dip to the foliation and to the veins. They are not entirely foliation-plane faults, for in places they crosscut the foliation, commonly at an acute angle. The faults tend to crosscut but are diverted along foliation planes because the preexisting surfaces offer less resistance than the direction of maximum resolved shearing stress. Movement along foliation planes continues until the stress at an angle to foliation becomes greater than the strength of the rock. Rupture then occurs across the foliation. In a similar manner the faults appear to be diverted along the wall of the veins for some distance before they rupture the vein. In a scale-model experiment, Ekkernkamp (1939) found that planar structure at 20° from the direction that fractures would normally follow in a homogeneous material would control almost completely the direction of fracture. Where the fractures did transect the foliation, the direction about bisects the angle between the normal to the foliation and the direction that would be taken in a homogeneous rock. Similar experiments were made with the planar structure at 45°, 60°, and 75° to the normal direction of fracture. Each had an effect on the direction of fracture, but the effect decreased as the angle increased. At 45° fully half the fractures occurred parallel to the planar structure, but at 75° the fractures crosscut without much visible control by the planar structures.

The fault at the north end of the 800 level and the faults north of coordinate 4200 N., 900 level, so far as known, have not displaced the vein, although some displacement could occur without being noticeable at the present state of development in these two localities. By analogy with other faults of similar attitude in the mine, they are probably reverse faults. Offsets of the vein on these faults may appear as development and mining progresses. A gouge zone, 4 to 12 inches thick, marks the fault within the vein on the north 800 level. It is not known whether this gouge represents an original schist parting which has been sheared or whether it is material moved into place by faulting. This fault has not been located on the 700 level; on the north 900 level it is probably the fault on the hanging wall of the vein, and if so, has not disrupted the vein to any large extent (pl. 6). On the 900 level the fault is marked by a gouge zone up to a foot in width. The fault in the footwall at the north end of the 900 level is marked by a strong gouge zone about three feet from the actual wall of the vein. This fault is not known on higher levels, and development on the 1000 level had not extended far enough north to encounter it.

The Iron King fault, which is steeper than the veins, has duplicated the I vein on the 700, 800, and 900 levels (pls. 4 and 5). It lies in the footwall of the I vein on the 1000 level; apparently movement has occurred between the I and H and between the H and G, as the veins are much closer together than elsewhere and much gouge is in the intervening wallrocks. The fault dies out both to the north and to the south from a central point where the vertical displacement is about 100 feet. Figure 8 shows the offset of the vein in three equally separated sections. Section Z - Z' illustrates the fault near the north end of the mine where it begins as a small fault breaking a small fold in the vein. The fold extends some distance north of the fault. The axis of the fold is approximately parallel to the line of intersection of the footwall segment of the vein with the fault plane. Section Y - Y' is through the zone of maximum vertical displacement, and Section X - X' illustrates the decrease in vertical displacement on the fault toward the south.

At about 3880 N. on the 900 level the Iron King fault is cut by a reverse fault flatter than the veins. This fault has displaced the D vein about 10 feet vertically near coordinate 3440 N., as shown in a raise from the 1000 to the 900 level. No counterpart of this fault was found in the hanging wall of the Iron King fault; hence

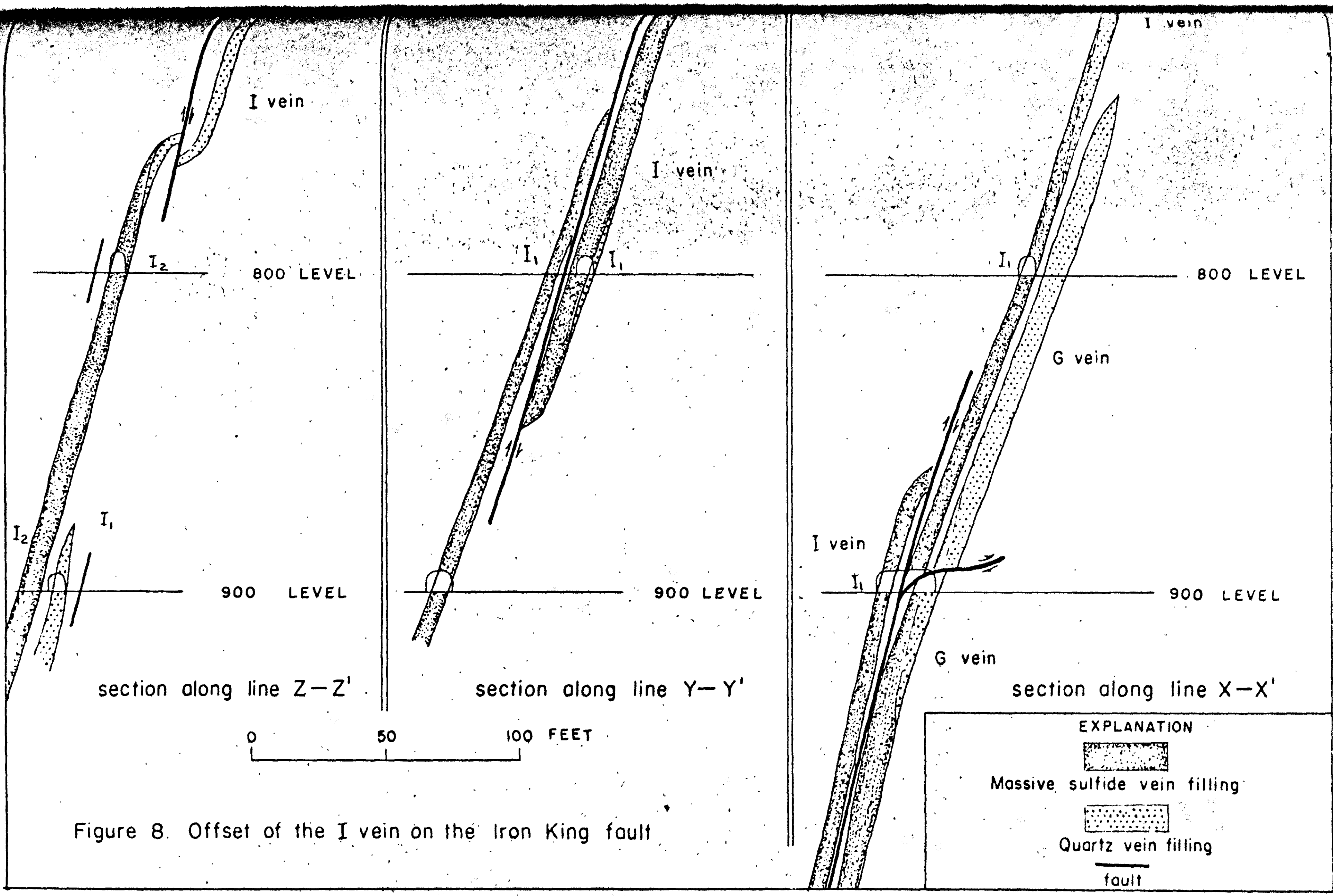


Figure 8. Offset of the I vein on the Iron King fault

it is assumed to be essentially contemporaneous with the Iron King fault. This fault intersects a reverse fault that is steeper than the vein at 3360 N., 900 level. The steeper fault has duplicated the D vein between 3200 N. and 3300 N., and its relations to the veins and the adjacent flat fault are shown in figure 9. From 3100 N. to the south end of the 900 level, the workings expose a reverse fault flatter than the vein. At about 2920 N. this fault has a vertical displacement of about 10 feet between the 800 and 900 levels. Conceivably this fault and the one that occurs between 3900 N. and 3360 N., 900 level, could be offset parts of the same fault, as both have the same general attitude and amount of vertical displacement.

Only the faults that dip steeper than the veins will affect the veins in depth. On the 1000 level the Iron King fault lies between the I and H and between the H and G veins. Development work has not proceeded far enough south on the lower levels to expose the steep fault that lies south of No. 6 shaft. The faults that are less steep than the veins transgress all the veins between the 900 and 1000 levels and rake either gently southward or nearly horizontal. They probably will not be encountered again.

Here and there in the veins are small faults (not shown on maps) that range in strike from N. 85° W. to N. 80° E. and dip south at about 80° wherever the dip could be measured. The most striking feature of these faults is that commonly the fault planes stop at the walls of the veins, yet gouge up to 6 inches in width, composed

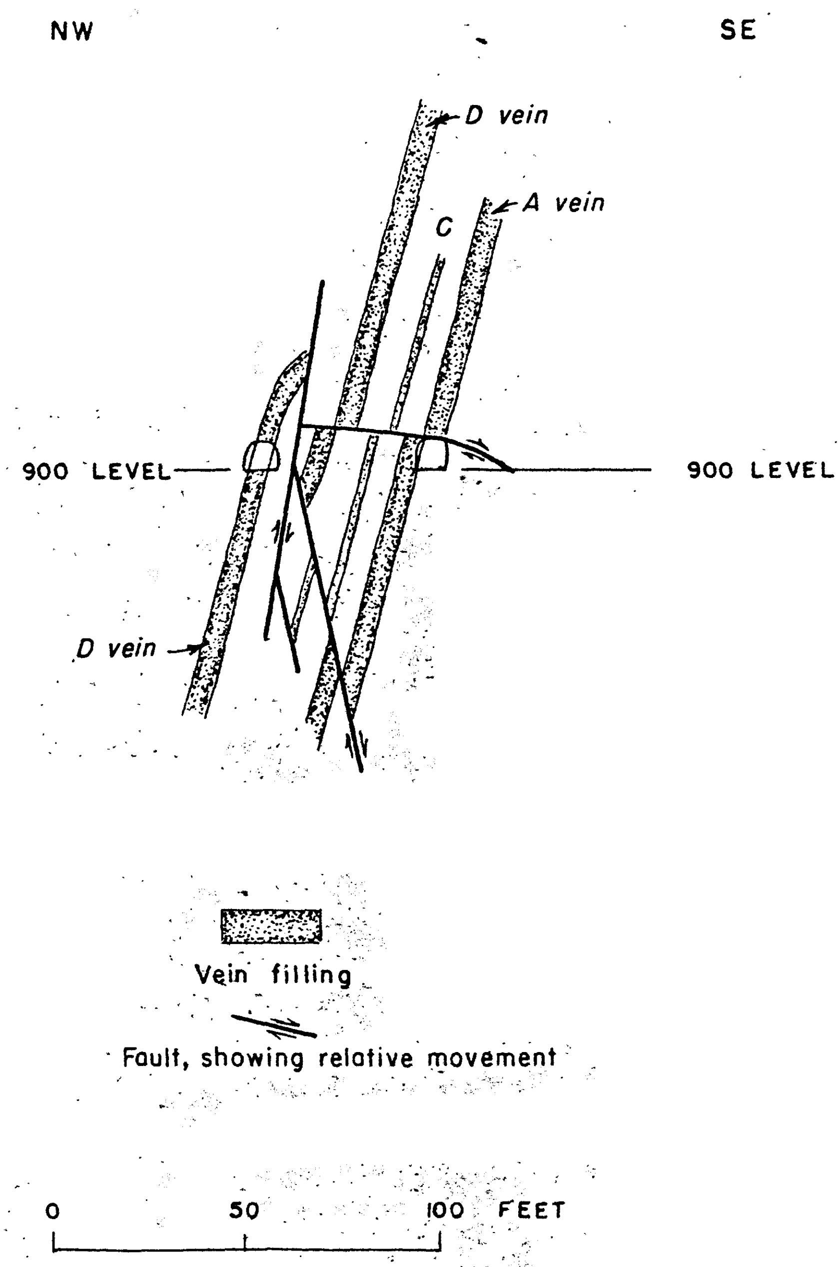


Figure 9. Section showing nature of displacement of veins on faults at 3288 N., 900 level

of pulverized vein filling, is present. Generally the faults occur as several closely spaced parallel breaks. In several places they extend into the wallrock and a small horizontal displacement was observed; in all such occurrences the north wall moved east relative to the south.

There is no way of measuring the displacement on these faults, although it is probably small, as the faults do not mark changes in grade or appearance of ore from one wall to the other. Where the faults do not cut the wallrocks, they may represent minor adjustment to postmineral deformation, wherein the veins moved slightly within the confines of the vein walls.

Flat joints, essentially at right angles to the dip of the veins, are abundant throughout all the veins. They are spaced only a few feet apart vertically.

In the fine-grained, well-foliated hydrothermal alteration zones in the Iron King area slip cleavage is very abundant. As the slip cleavage is somewhat varied in attitude, 58 attitudes were measured from outcrops scattered at random throughout the alteration zones. Only one attitude of slip cleavage was recorded at any one outcrop. The poles to the planes of the slip cleavage were plotted on a stereographic net revealing a 25 percent concentration of planes at N. 60° W., 70° SW. and a 12 percent concentration of planes at N. 75° E., 70° SE. The slip cleavage has two distinct forms, (1) a series of "V-shaped" minor folds having fractures bisecting the folds, and (2) sigmoid folds having sharp bends and a fracture bisecting the angle at each bend. Using the direction of relative movement indicated by the sigmoid-type cleavage, the north side of the N. 75° E. slip cleavage apparently moved toward the southwest, and the north side of the N. 60° W. slip cleavage apparently moved toward the southeast. Thus they moved in the proper sense to be members of a conjugate set of shears. In plan view the two directions of cleavage are nearly symmetrical with the strike of the veins, and it might be assumed that the fracture cleavage and faults that localized the veins were related to the same deformation. However, in three dimensions, the deformation plane of the slip cleavage (ac plane of the structural coordinate system) is far removed from either of two deformation planes, inferred by assuming that the lineation in the vein walls is either the "a" or "b" direction of the structural coordinates. Thus the slip cleavage is probably of postmineral age, possibly due to the deformation that produced the postmineral faults in this mine.

REFERENCES

Barth, T. F. W., Correns, C. W., and Eskola, P., 1939, Die Entstehung der Gesteine: Springer, Berlin, S. 357-359.

Bateman, A. M., 1927, Ore deposits of the Rio Tinto (Huelva) district, Spain: Econ. Geol., vol. 22, no. 6, pp. 569-614.

Capps, S. R., and Johnson, B. L., 1915, The Ellamar district, Alaska: U. S. Geol. Survey Bull. 605, pp. 87-92.

Ekkernkamp, M., 1939, Zum Problem der altern Anlagen in Bruchgebieton: Geol. Rundshau. 30, S. 713-764.

Finlayson, A. M., 1910, The pyrite deposits of Huelva Spain: Econ. Geol., vol. 5, no. 5, pp. 403-437.

Graton, L. C., 1909, The occurrence of copper in Shasta County, Calif.: U. S. Geol. Survey Bull. 430, pp. 71-111.

Gilluly, J., 1933, Replacement origin of the albite granite near Sparta, Oregon: U. S. Geol. Survey Prof. Paper 175-C, pp. 65-81.

Hanson, G., 1920, Some Canadian occurrences of pyritic deposits in metamorphic rocks: Econ. Geol., vol. 15, pp. 574-609.

Harker, A., 1939, Metamorphism, 2d ed., p. , London,

Hendricks, H. R., 1947, Milling lead-zinc ores at the Iron King mine, Prescott, Arizona: Am. Inst. of Min. and Met. Eng., Mining Tech., vol. 11, no. 4, T. P. 2191.

Hutton, C. O., 1940, Metamorphism in the Lake Wakatipu region: New Zealand Dept. Sci. and Industr. Res., Geol. Mem., no. 5.

Jaggar, T. A., and Palache, C., 1905; U. S. Geol. Survey Geol. Atlas, Bradshaw Mountains folio (no. 126).

Lasky, S. G., 1936, Geology and ore deposits of the Bayard area, Central mining district, New Mexico: U. S. Geol. Survey Bull. 870.

Lindgren, W., and Irving, J. C., 1911, The origin of the Rammelsberg ore deposit: Econ. Geol., vol. 6, pp. 303-313.

Lindgren, W., 1926, Ore deposits of the Jerome and Bradshaw quadrangles, Arizona: U. S. Geol. Survey Bull. 782.

Mills, H. F., 1941, Ore occurrence at the Iron King mine: Eng. and Min. Jour., vol. 142, no. 10, pp. 56-57.

__________, 1947, Occurrence of lead-zinc ore at the Iron King mine, Prescott, Arizona: Am. Inst. of Min. and Met. Eng., Mining Tech., vol. 11, no. 4, T. P. 2190.

Mining World, 1944a, Mining at the Iron King: Mining World, vol. 6, no. 3, pp. 13-16.

Mining World, 1944b, Iron King milling practice: Mining World, vol. 6, no. 4, pp. 21-24.

Ransome, F. L., 1903, Geology of the Globe copper district, Arizona: U. S. Geol. Survey Prof. Paper 12, p. 15.

__________, 1919, The copper deposits of Ray and Miami, Arizona; U. S. Geol. Survey Prof. Paper 115.

Reber, L. E., Jr., 1938, Jerome district: Arizona Bur. Mines Bull. 145, pp. 41-65.

Schouten, C., 1934, Structures and textures of synthetic replacements in "open space": Econ. Geol., vol. 29, no. 7, pp. 611-658.

Schwartz, G. M., 1947, Hydrothermal alteration in the "Porphyry Copper" deposits: Econ. Geol., vol. 42, no. 4, pp. 319-352.

Short, M. N., Microscopic determination of the ore minerals: U. S. Geol. Survey Bull. 914.

Stevenson, J. S., 1937, Mineralization and metamorphism at the Eustis mine, Quebec: Econ. Geol., vol. 32, pp. 335-363.

Swanson, C. O., and Gunning, H. C., 1945, Geology of the Sullivan mine: Canadian Inst. Min. Metallurgy Trans., vol. 48, pp. 645-667.

Turner, F. J., 1948, Mineralogical and structural evolution of the metamorphic rocks: Geol. Soc. Am. Mem. 30.

Wilson, E. D., 1939, Pre-Cambrian Mazatzal Revolution in Central Arizona; Geol. Soc. Am., Bull., vol. 50, pp. 1113-1164.

Winchell, A. N., 1933, Elements of optical mineralogy, 3d ed., p. 74.