Nine Strike mine. As observed in thin section this rock is composed of tabular basaltic hornblende and lath-like labradorite phenocrysts set in a fine-grained to glassy matrix in which skeletal crystals of augite and magnetite could be identified. This dike resembles the camptonite dikes described by Lindgren (1926, p. 144) in the Bradshaw Mountains, about 25 miles to the southeast. Other fine-grained basic dikes, including diabase, lamprophyres, and dense black basaltic-type dikes, can be seen along the road to Prescott on the east side of Copper Basin. No spatial relation of any of these dikes to the Copper Basin stock could be determined and those that are not Precambrian in age may be associated with the late Tertiary vulcanism in the region.

Late Tertiary (?) Rocks

General statement

Rhyolite rocks in the area include a volcanic neck, two rhyolite plugs, numerous dikes, and one small exposure of bedded tuff, (Plate X).

Definite evidence is lacking for the age of the rhyolitic rocks. The rhyolite intrusives cut all the Copper Basin stock rocks and associated mineralization, and there is evidence that a period of erosion separated the two general periods of igneous activity. The bedded tuff unit indicates an origin in deposition from water; thus there has been little change in some of the surface features near the volcanic neck. The rhyolite plugs and dikes are composed of about 10 percent phenocrysts and 90 percent glassy groundmass. The texture indicates a more near-surface environment than do the textures of the Copper Basin stock. Lake beds, containing rhyolitic tuff interbeds, near Goodwin, about 20 miles south of Copper Basin, have been dated as Pliocene by camel remains. This may represent a general period of acid vulcanism in the region, and hence the rhyolitic rocks of the Copper Basin area are tentatively classified as late Tertiary (?) until more specific evidence is found.

Rhyolite Tuffs

A bedded unit, consisting primarily of fine to coarse-grained rhyolitic sand and included agglomeratic or pyroclastic material, is best exposed in Finch Wash at the east contact of the volcanic neck. The exposed area extends about 2000 feet north by 1000 feet east. The beds strike N. 30°-40° E. and dip 10°-40° NW. towards the volcanic neck. A few remnants of similar material were observed on the west side of the neck and in that area the dip is east toward the neck. Much of the unit is covered by talus from the neck, but a thickness of at least 200 feet is indicated.

Much of the unit is represented by individual beds, ranging from $\frac{1}{4}$ to 6 inches thick, and composed of fine to coarse-sized, angular to sub-angular, siliceous grains. The individual beds commonly show graded bedding (Plate VI-B). Other beds ranging from 2 to 6 feet thick are not well-stratified and consist of angular to locally rounded fragments of rhyolite mixed with Precambrian metamorphic and granitoid rocks in a fine to coarse-grained matrix of clastic siliceous material containing some clay bands. Impact structures, as indicated by sharp down-bending of thin beds under fragments, were observed in the unit. Small scale unconformities are present in the thinner-bedded portions of the unit (Plate VI-B).

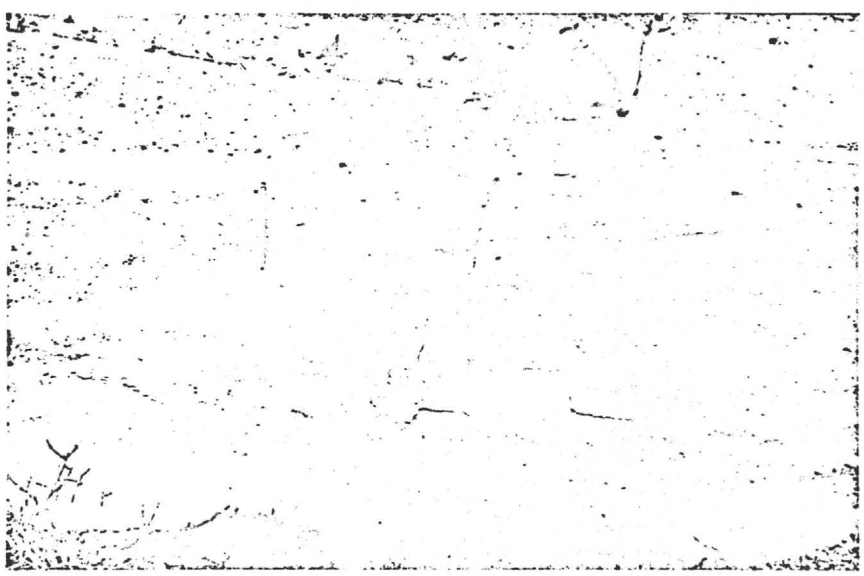
A search for microfossils in the thinly bedded material gave negative results.

The exact origin of the bedded tuff is in doubt, but it was probably formed early in the history of the volcanic neck. The vent may have originally formed by explosive action which resulted in an early crater, pit, or maar at the surface. Tuffaceous material was then reworked by a mixture of juvenile and meteoric water in a lake formed within the crater. Subsequent eruption of rhyolite and pyroclastics incorporated the central part of the bedded tuff and left only remnants along the outer edges. Final subsidence of the main neck tilted these remnants in towards the center.

Rhyolite

High rugged buttes, forming a prominent landmark on the west side of the area, comprise a volcanic neck of pyroclastic

A. Late Tertiary (?) rhyolite volcanic neck.
View west from Copper Basin road.



B. Late Tertiary (?) tuffaceous bedded sediments.
Small angular unconformity in center area.
View of west bank of Finch Wash.

material and intrusive rhyolite (Plate VI-A). The neck is roughly a half mile in diameter. Two rhyolite plugs crop out in Copper Basin; one is in the center of the quartz monzonite unit, and the other forms a northerly-trending ridge on the west side of the basin (Plate IX). Rhyolite dikes connect the plugs with the volcanic neck. A swarm of rhyolite dikes, generally striking north to N. 70° W., is present in the southwest part of the area.

In general the rhyolite is resistant to erosion; the plugs and volcanic neck form prominent buttes or rounded hills, and the dikes commonly stand 10 to 50 feet above their surroundings as resistant ribbon-like outcrops. The rhyolite weathers a light gray or reddish brown, the difference depending on the amount of iron-staining.

The volcanic neck is a mixture of breccia, blocks of bedded tuff, and much intrusive rhyolite. No attempt was made to unravel the detailed sequence of events, but at least two generations of rhyolite are present. Steep flow structures were observed in many parts of the neck. Elliptical openings are common and range from pea size to 6 inches in diameter. Some are common gas vesicles, but many were formed from the weathering out of soft, yellow clay fragments.

The plugs in Copper Basin are composed, for the most part, of uniform, light gray rhyolite. Locally a purple rhyolite, represented by dikes ranging from 6 inches to 3 feet wide, cuts the light gray rhyolite. Swirling, steep flow structures are common in both plugs. The floor of Copper Basin has been eroded to a depth of at least 300 feet felow its position when the plugs were emplaced.

A general zone of rhyolite dikes, striking N. 50°-60° W., connects the west plug and the volcanic neck. The dikes range from 5 to 50 feet wide and are commonly discontinuous along the strike. Some dikes are massive fine-grained rhyolite and others contain breccia and porous rhyolitic material.

Rhyolite and rhyolite breccia dikes are numerous enough in the southwest corner of the area to be classed as a "swarm". These dikes generally strike north to N. 70° W., and have vertical or steep dips. Some of these dikes have a distinctly purple groundmass and others are light gray. In some areas light gray rhyolite was observed as breccia fragments in a purple rhyolite matrix. Intrusive rhyolite breccia dikes rarely exceed 500 feet in length and commonly grade into normal rhyolite along the strike. Some of the breccia may represent explosive types, but hot spring deposits of iron-stained chalcedonic quartz and calcite obscure the details.

The rhyolite in the neck, plugs, and dikes is relatively uniform in texture and composition as observed in the field and in thin sections. The rock consists of from 5 to 15 pergroundmass. The phenocrysts are composed of various proportions of sanadine, quartz, albite, and biotite. These minerals are all present as euhedral crystals except quartz which is in the form of doubly terminated crystals and irregular rounded grains. The aphantic matrix grades from microgranular to glassy. The glassy groundmass has an index less than balsam and commonly contains numerous microlites and crystallites.

Quaternary Deposits

Deposits included in this unit are surficial accumulations of unconsolidated or semi-consolidated alluvium, terrace gravels and mantle rock.

Stream terrace material associated with Copper Basin Wash and tributary streams is irregularly distributed on the floor of Copper Basin. However, bedrock exposures were numerous enough to indicate the igneous units on the map instead of the terrace gravel (Plate X). The terrace gravel is composed of a heterogeneous mixture of material ranging from rounded stream boulders 3 feet in diameter to matrix material of coarse to fine-grained sand and clay. The terraces attain a maximum thickness of 35 feet.

The Quaternary unit mapped in the southwest corner of the area is dominantly a mantle rock cover and local alluvium. The narrow strip along the northwest side of the map represents a mantle-covered pediment and local alluvium along stream valleys.

STRUCTURE

General Statement

The absence of sedimentary marker beds and definite age determinations imposed many obstacles in the presentation of a definite structural picture. However, by use of regional data, intrusive relations, and association of certain types of ore deposits a tentative structural interpretation has been made. Certain dike rocks bearing a specific age relation to either the Copper Basin stock or late Cretaceous (?) or early Tertiary (?) age or to late Tertiary (?) rhyolite, were indispensable in some structural interpretations. Some of the faults probably have had a long and complex history that could only be worked out in part.

Precambrian Structures

Folding and foliation

Anderson (1951, -. 1345) sums up the trends of folds in older Precambrian rocks in the Little Dragoon Mountains, Mazatzal Mountains, Bagdad, and Prescott area (Plate III) as follows:

> "The trend of the folds is northwest, north or northeast, indicating general east-west compressive forces during the orogeny."

In the mapped area the general trend of the folds is N. 10°-30° E. Bedding-foliation in areas undisturbed by intrusions exhibits this strike and dips 60°-80° NW. These structures have imparted a regional "grain" to the country and exerted a profound influence on the subsequent intrusive and structural history. Whether the metasediments and the volcanic portion of the amphibolite exposed in the area represent a homoclinal or isoclinal sequence is unknown. The exposure of metasediments south of the Boston-Arizona mine is lithologically different from the metasediments in the northwest corner of the area. Furthermore, evidence for the direction of tops of beds was not found and there may be some overturning.

Where low grade regional metamorphism predominates, foliation is essentially parallel to bedding. In contact metamorphic areas the bedding is generally visible, but the foliation has usually been destroyed. Although numerous shear and fracture zones were observed, fracture cleavage showing a relation to folding was not distinguished. The bedding-foliation in the metasediment and amphibolite units shows radical departures from the regional trend near many of the intrusive contacts. However, in other places the regional foliation continues from the bedded units into the granitic rock without any change in strike or dip (Plates IV and V).

The origin of "gneissoid" foliation in the granitic rocks has been discussed, to a certain extent, under the description of the rock units. Many of the smaller igneous bodies are elongated parallel to the regional foliation and are in part concordant (Plate X). In these bodies the foliation probably represents primary flow structure, and in some cases, superimposed regional metamorphism. Except for border zones, the foliation in larger masses is weak and commonly absent.

In reference to the individual older Precambrian units, the foliation in the quartz diorite, and possibly in the granodiorite porphyry may represent one or all of the following: primary flow structure, regional metamorphism, inherent foliation from replacement of older rocks, or local dynamic metamorphic effects. Regional metamorphism probably did not have a profound effect on the granodiorite porphyry unit, since the hornfelsic texture of the contact metamorphic aureole was not materially changed. It appears that the granodiorite unit was intruded essentially at the end of the orogenic period. Foliation in this unit, where present, is probably due to primary flow structures and cataclastic deformation by subsequent intrusions.

Faults

Faults to which a Precambrian age can be assigned are restricted to fractures now occupied by veins and dikes recognized as Precambrian in age.

Two distinct fault-fissure systems are represented by tourmaline-quartz veins; one strikes N. 60°- 75° W. and the other strikes N. 55°-75° E. Both sets generally have steep northerly dips. The first set is well-developed in the vicinity of the Gold Star mine and the other set is prominent in Finch Wash (Plate X). The displacement along these faults is probably not large, because no offset could be determined at gradational contacts between rock units.

It is probably that some major Precambrian faults have been obscured by emplacement of the granitic units. It is also likely that some of the faults having later movements were initiated in Precambrian time.

Structures Older than the Copper Basin Stock

Several prominent faults, well-exposed in the north half of the area, strike N. 10°-50° E., and dip vertically to steeply northwest. Since these faults strike essentially parallel to regional foliation, it is impossible to determine the magnitude of displacement unless a transverse feature is present. Local schistose zones in many of the weaker beds indicate much structural adjustment in this general direction.

Structures of this general trend cut all of the Precambrian rock units. One fault, paralleling Finch Wash, offsets a tourmaline-quartz vein a horizontal distance of 2000 feet (Plate X). Inasmuch as tourmaline-quartz veins have been found in all of the Precambrian rocks, a lower limit for the age of this fault is indicated. This same fault, named the Finch fault, does not offset a quartz latite dike associated with the Copper Basin stock (Plate X). This indicates that the Finch fault pre-dates the intrusion of the Copper Basin stock.

A prominent northeast-striking fault in the northwest corner of the map area is expressed by a strong shear zone and iron-staining. It is only exposed in the amphibolite unit and the magnitude of displacement could not be determined.

A strong lineament extending N. 10° E. from the north end of Copper Basin is expressed by parallel drainage and some differences in rock types on opposite sides (Plate X). The southward extension of the lineament coincides with the long axis of the composite Copper Basin stock. Many later faults and dikes within the Copper Basin stock exhibit this general trend. Although definite evidence is lacking, the lineament may represent a regional fault of considerable magnitude.

Structures Associated with the Copper Basin Stock

Structural control of intrusions

Structural controls for the emplacement of the Copper Basin stock rocks comprise the regional foliation direction, N. 10°-30° E., and a contact between rocks of different competency.

The longitudinal axes of the quartz monzonite and quartz monzonite porphyry units and the trend of one group of quartz latite porphyry dikes parallel the regional foliation direction. A fault of unknown magnitude, exposed at the north end of Copper Basin, also parallels and coincides with the direction of the axes. Several quartz latite porphyry dikes in the southwest part of the area trend N. 25° E. and more or less coincide with the southward extension of the quartz monzonite porphyry axis. However, the south extension of the quartz monzonite axis trends due south and lies east of the dikes (Plate X).

The Copper Basin stock rocks were intruded at the junction of several older Precambrian units. This junction may have served as a structural locus for point of entry. The large granodiorite mass along the east side of Copper Basin may have acted as a stable block which served to concentrate structural deformation along the west border. The northwest-trending granodiorite porphyry band forms a "transverse" element in relation to the regional grain in the vicinity of the Copper Basin stock, and the place where it takes off from the

Basin stock, and the place where it takes off from the large granodiorite mass may have served as the dominate control for the point of entry of the Copper Basin composite stock.

The shape of the composite stock in depth is of importance in interpretation of certain structures and relation of ore deposits. The relief along the east side of Copper Basin has given certain clues to this shape. The east contact of the quartz monzonite unit dips 45°-60° west toward Copper Basin. The contact of this same body along the west side of the basin is essentially horizontal and represents the roof of the intrusive (Plate X, section B). If this contact is projected east, it appears that the top of the stock was not far above the present floor of Copper Basin. The west contact of the intrusive is represented by quartz monzonite occupying an east-dipping thrust fault about a mile west of Copper Basin. The thrust, named the Navy thrust, and the included quartz monzonite dip from 10° to 50° east toward Copper Basin. These data suggest that the quartz monzonite intrusive is a funnel-shaped stock or ethmolith having a restricted "nozzle" or "root" occupying a central position and extending in depth to an underlying magma chamber. The root is visualized as being elliptical in plan and having an elongation in a N. 10° - 20° E. direction, parallel to the trend of of the stock at the surface.

The individual intrusives of the composite stock are visualized as having pushed their way up through the restricted orifice and expanded in the direction of least resistance at that particular time.

The earliest intrusion, the diorite, was in part controlled by a west-trending fault (Plate X). Later the quartz monzonite was intruded in the zone east of the diorite. This larger mass was restricted on the east by the blocky Precambrian granodiorite. Consequently it spread out to the north and to a lesser degree to the south. Lateral space was provided by westward thrusting of the west wall which initially developed the Navy thrust fault, and later the magma was intruded into the fault plane and wedged up the upper plate from the lower one (Plate X, section B). A 300-700 foot shear zone gradually passes into a fracture system which trends westward across the foliation and parallel to the intrusive contact.

Subsequently the quartz monzonite porphyry moved up along the north side of the orifice, split the earlier quartz monzonite, and then spread out northward (Plate X). Closely related in time, but following a period of minor structural adjustment, quartz latite porphyry dikes were intruded. One important dike trend coincides with the axis of the preceding quartz monzonite porphyry body and extends southward to the edge of the mapped area (Plate X).

After minor aplite injection, mineralizing fluids permeated the country, and the resultant deposits exhibit a definite pattern controlled by the above-mentioned structural features.

Navy thrust fault

The thrust fault, apparently formed by lateral forces exerted by the Copper Basin stock, is expressed on the surface as an irregular-shaped arc. The concave side of the arc faces Copper Basin. The fault can be traced from an inclined shaft located about 1500 feet north of the Copper Basin road, westward to the U. S. Navy mine (Plate X). West of the U. S. Navy mine the fault zone is occupied by quartz monzonite. From a high ridge about a half mile west of the above mine, the fault swings southeast toward the Mint mine. The exposures are poor in this area and the fault was not discernable about a quarter of a mile northwest of the Mint mine.

The thrust fault is best-exposed in the adit-level at the U. S. Navy mine where it strikes N. 70°-80° E. and dips 20°-45° S. Hard slick walls of Precambrian quartz diorite are separated by 2 to 4 feet of mineralized gouge and quartz-carbonate vein material. Some of the gouge represents sheared quartz monzonite of the Copper Basin stock.

The initial thrust plane was probably former by lateral forces exerted by intrusion or the quartz monzonite. Later the quartz monzonite intruded the thrust zone and wedged the upper plate from the lower. Subsequent thrusting sheared and brecciated parts of the enclosed quartz monzonite.

The thrust and the associated quartz monzonite cut across Precambrian quartz diorite and granodiorite. The contact between these two Precambrian units is so gradational and poorly exposed that the magnitude of displacement of the thrust could not be determined. The foliation in the upper thrust plate is strongly deformed and commonly dips east in contrast to the regional west dip.

Smaller subsidiary flat faults were noted in vicinity of the Navy thrust fault. The Silver Gulch mine exploits one of these flat faults.

Boston fault zone

The Boston fault zone extends from the Boston-Arizona mine south about 3 miles to a group of shallow pits and short adits located about 1500 feet east of the McNary mine (Plate X). Another fault is present on this trend about one mile farther south and may represent an extension of the zone.

The Boston fault zone comprises several parallel or subparallel fault strands which converge and diverge along the strike at irregular intervals. The separate faults could only be located definitely in a few places and the zone was traced as a unit. The magnitude and direction of displacement changes along the strike, and there is evidence of more than one period of movement. The relative horizontal displacement was determined by offset of igneous contacts and dikes. In the Boston-Arizona mine there is evidence from drag and striae of a strong vertical component of movement along one strand within the zone. Inasmuch as the Boston fault zone is one of the main structural controls for ore mineralization associated with the Copper Basin stock, it may have had at least partial origin in structural adjustments of the underlying magma chamber. A second period of adjustment is shown by post-mineral faulting in the Boston-Arizona mine.

In the vicinity of the Boston-Arizona mine the fault zone strikes about N. 25° W. and the separate strands dip from 85° E. to 55 W. The fault could not be found more than 1000 feet north of the mine, but a faint lineament on the photos could be traced for about another mile. A quartz porphyry dike, which intersects the fault zone in the vicinity of the mine, has been offset 1500 feet; the west segment moved south (Plate X).

South of the Boston-Arizona mine the fault zone assumes a more southerly trend and can be traced continuously to the east side of the rhyolite volcanic neck. Displacement of a granodiorite porphyry contact in this vicinity indicates a horizontal displacement of about 600 feet; the west side moved south relatively (Plate X).

The fault zone was next found about a mile to the south or about 1000 feet south of the U. S. Navy mine. The relation of the Boston fault zone to the Navy thrust is obscure, but the projected intersection falls in the vicinity of the old stopes at the U. S. Navy mine.

South of the U. S. Navy mine and about 1500 feet east of the McNary mine, the fault zone is well-exposed in prospect pits and shallow shafts. Here one fault strand offsets the Copper Basin quartz monzonite about 600 feet; the west wall moved south.

About one mile farther south a fault on the same trend offsets a rhyolite dike.

Minor faults and joint systems

Faults of small displacement are associated with and parallel to most of the previously discussed structures. Certain minor faults are of importance as ore controls within or near the Copper Basin stock rocks. These faults represent minor adjustments after solidification of the now-exposed portion of the stock and before, during, and after mineralization. The prominent faults of this type strike in the following directions:

1. N. 20° - 30° W.
2. N. 20° - 40° E.
3. N. 70° - 80° E.
4. N. 60° - 80° W.

Many of these faults are filled by quartz and sulphides, but some formed after mineralization had ceased. Minor regional adjustment probably initiated these faults, but is is likely that some subsequent movements were caused by either shrinkage due to crystallization in the magma chamber or further upward movement of the magma.

Prominent joint sets are parallel to the four fault or fracture directions listed above. However, many of the joints within the Copper Basin stock have random orientation which is probably due to the complex intrusive history of the stock or the subsequent rhyolite intrusions in the same area.

Breccia pipes

Approximately 25 nearly vertical pipes, roughly circular or elliptical in plan, are associated with the Copper Basin stock rocks. The origin of these pipes is treated under a subsequent major heading.

Structures Related to Late Tertiary (?) Rhyolite

The rhyolite exposed in the Copper Basin area represents near-surface intrusions which were intruded into pre-existing structures. The two plugs in Copper Basin probably moved up along one side of the "root" of the Copper Basin stock. The rhyolite volcanic neck was localized in a zone of weakness at the intersection of several Precambrian rock types, the Finch fault, and the Boston fault zone (Plate X). Another line of weakness is represented by several rhyolite dikes, striking S. 50° W., which connect the neck with the easternmost rhyolite plug in Copper Basin. The multitude of rhyolite dikes in the southwest corner of the map area trend in several directions, but those striking north to N. 60° W. are predominant.

Post-Rhyolite Structures.

Faults offsetting the rhyolite were observed in several places. The maximum displacement measured was an apparent horizontal offset of about 400 feet along an east-striking fault which cuts the south extension to the rhyolite plug in the center of Copper Basin (Plate X). Minor faults striking N. 30° E. displace the rhyolite dikes along the Copper Basin road southeast of the volcanic neck. Some of the post-mineral faulting in the mines may be associated with this episode of deformation.

ORIGIN OF BRECCIA PIPES

General Statement

About 25 breccia pipes are associated with the Copper Basin stock rocks (Plates X and XI). A cluster of round, reddish brown hills on the west side of Copper Basin, immediately north of the Copper Basin road, comprise the main group of breccia pipes (Plates II-B and IX-A). The Commercial, Copper Hill, and Loma Prieta mines have exploited three separate breccia pipes to depths ranging from 300 to 600 feet from the surface. The Commercial mine has supplied most of the copper production from the district. Other pipes in this group have been developed by pits, shallow shafts, and short adits.

Some pipes are distributed south from the main cluster along the west side of Copper Basin to the south border of the mapped area. These pipes are not as well-defined as the ones to the north and none have been productive. Irregular alteration areas containing minor breccia are present west of Copper Basin in the vicinity of the Mint mine and along the Boston fault zone where it intersects the Copper Basin quartz monzonite, 1,500 feet east of the McNary mine (Plate X).

Description

Shape

Most of the pipes are nearly vertical columnar bodies having a roughly circular or elliptical plan, although some pipes have irregular tongues projecting out from one side. The pipes range in maximum diameter from 50 to 600 feet. The largest one, having a diameter of about 600 feet, is the Commercial pipe. The Loma Prieta and Copper Hill mines have explored pipes approximately 300 feet in diameter.

Vertical changes of shape could not be determined since the underground workings, with the exception of a few adits, were either caved or flooded at the time of examination in 1952. However, the small vertical interval that could be examined suggests that the pipes may be expected to show considerable irregularities with depth. A few small breccia pipes appear to bottom on flat faults. It is not known whether the pipes formed along the flat faults or whether the flat faults offset the pipes after they were formed.

Most of the pipes are resistant to weathering and stand above the floor of Copper Basin as low round hills having a relief of less than 300 feet. However, the Loma Prieta pipe is located under terrace gravels east of Copper Basin Wash and shows no topographic expression. Several of the pipes have not been prospected and talus covers the slopes to the extent that the actual size and shape could not be determined.

Relation to enclosing rocks

The relation of the breccia pipes to the Copper Basin stock rocks and other rock units is of considerable importance in an overall interpretation of their origin.

The main breccia pipe group is clustered around the south end of the quartz monzonite porphyry intrusive. Some of the pipes are at the contact of this unit but none occur wholly within it. Several pipes, including the Loma Prieta, are entirely within the quartz monzonite unit and some, including the Copper Hill, are in the Precambrian quartz diorite. However it is known from diamond drilling at the Copper Hill mine that quartz monzonite underlies the pipes exposed in Precambrian rocks.

North of the Commercial pipe one small ill-defined pipe is exposed at the contact of aplite and quartz monzonite porphyry. The pipes in the south part of Copper Basin are entirely within quartz monzonite.

Fragments from all of the intrusive rocks of the Copper Basin stock were found in some of the pipes, thus indicating that pipe formation followed the intrusion of the stock rocks. In some pipes, entirely within the quartz monzonite, there is no evidence to indicate whether they preceeded or followed the intrusion of the later members of the Copper Basin stock rocks. The rhyolite dikes cut the pipes and associated mineralization and are obviously post-pipe in age.

The Copper Hill pipe is in gneissoid Precambrian quartz diorite at the surface, but the adit level exposes fragments of the Copper Basin stock which is known to underlie the deposit.

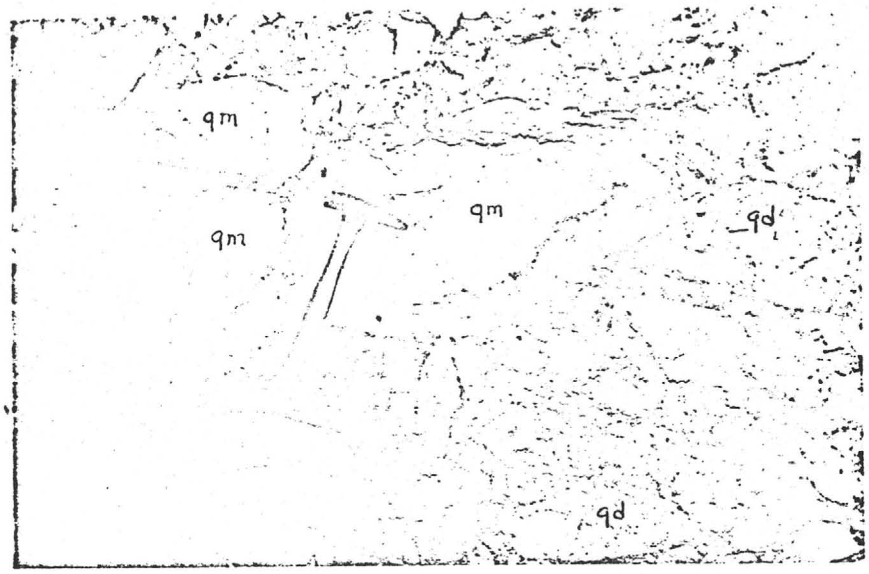
The main pipe at the Commercial mine is located at the junction of several rock types including Precambrian quartz diorite, and Copper Basin stock rocks comprising quartz monzonite, quartz monzonite porphyry, quartz latite porphyry and aplite.

The Loma Prieta pipe is in late Cretaceous (?) or early Tertiary (?) quartz monzonite and associated quartz latite porphyry dikes.

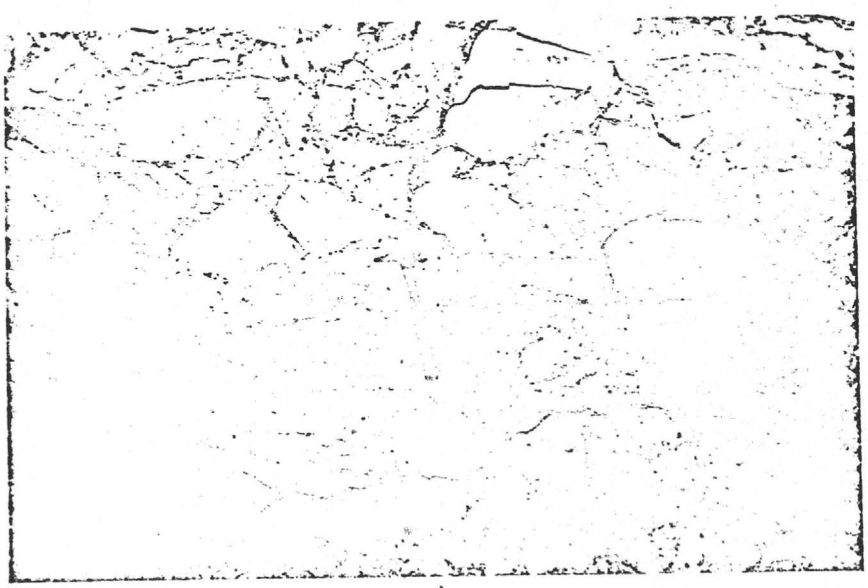
The spatial distribution of the pipes appears to be an important factor in the problem of origin. The main group of pipes, including all of the productive ones, are located directly above the postulated position of the restricted orifice or root area through which the separate magmas that developed the Copper Basin stock rocks are thought to have been injected. In detail this area is where the quartz monzonite porphyry moved up along the north side of the postulated root of quartz monzonite. The pipes in the south part of the basin may be associated with the southwest contact of the root.

Nature of fragments

Unfortunately only a few near-surface workings were accessible for examination in 1952; thus only the upper portions



A. Mixed rounded breccia fragments in Copper Hill adit level. Precambrian quartz diorite (qd) and late Cretaceous (?) or early Tertiary (?) quartz monzonite (qm) fragments.



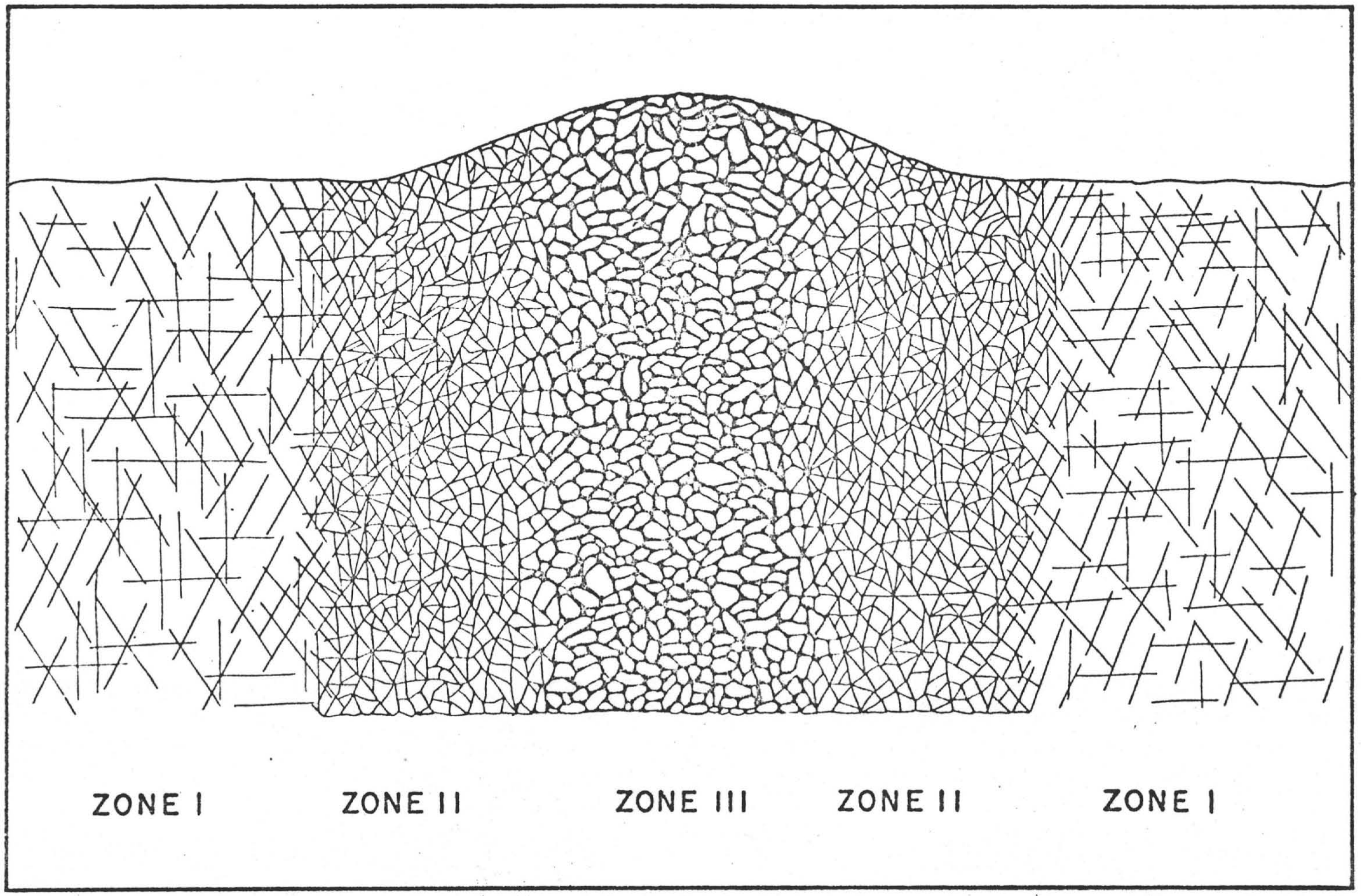
B. Quartz monzonite fragments in Copper Hill adit level. Dark cementing material is iron-stained quartz.

of the pipes could be studied in place. The study of undeveloped pipes from the surface is unsatisfactory since exposures are poor and the unsilicified portions have been obliterated by weathering. Dump fragments gave some impression of the different rock types, alteration, and nature of ore and gangue minerals in the deeper workings.

The individual fragments show wide diversity in size and shape within one pipe. The physical properties of the fragments are best understood by a discussion of the different zones shown on Plate VIII.

Zone I represents fractures and jointed ground surrounding the breccia pipes or what might be terned the "inter-pipe" area. This zone comprises closely-spaced joint and fracture systems which have been partially mineralized by vein quartz, pyrite, and copper sulphides. The quartz was deposited in open fractures or joints and replacement was minor. The country rock is weakly to moderately altered by leaching of the mafic minerals and some argillic alteration and sericitization of feldspars.

Certain sets of joints and fractures dominate within small areas, but no definite overall pattern was ascertained. The predominant joints and fractures range from about 3 inches to 3 feet apart. However, when the rock is broken with a hammer, numerous irregular, incipient, iron-stained cracks become apparent. There is little or no rotation of the joint and fracture blocks in Zone I.



IDEALIZED DIAGRAM OF BRECCIA PIPE

Zone I – Mineralized joint and fracture system. Zone II – Angular "crackle breccia" cemented by quartz and sulphides; no marked rotation or mixing of fragments. Zone III – Angular to rounded "rubble breccia" exhibiting marked rotation and mixing of fragments. Cementing materials (black) are quartz and sulphides. (Zones II and III, combined, range from 50 to 600 feet in diameter.)

PLATE VIII

Zone I is represented by an area of about one square mile that includes all of the pipes in the main north group (Plate XI). Local quartz-sulphide filled joints and fractures are present near the pipes in the south area but nothing was observed that would constitute a definite zone.

Zone II is characterized by angular to sub-angular fragments ranging from 1 inch to 10 feet in long dimension but averaging between 2-12 inches. There is no marked rotation of these fragments although considerable movement has taken place in parts of this zone, probably by settling but dilation may have been of some importance. Much of this zone resembles the stockwork breaking or "crackle breccia" of the porphyry copper deposits. A well-bounded fragment may be cut by a finer network of fractures.

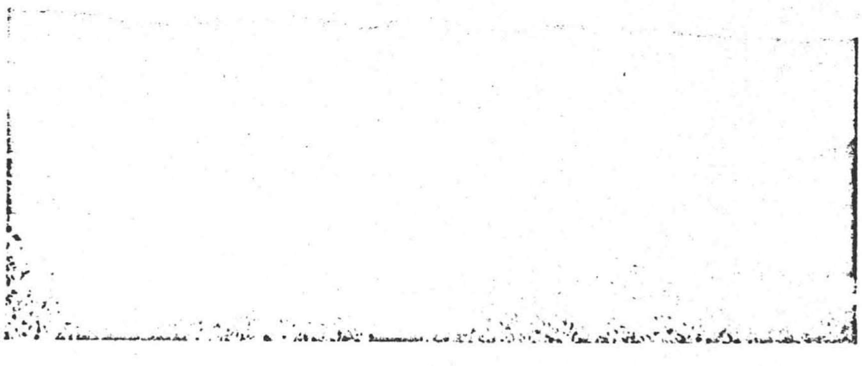
In some parts of Zone II the projected joint-fracture pattern of Zone I can be identified and in other places there has been enough non-rotational movement to obscure it. In general the size of the fragment is much smaller in Zone II than in Zone I.

In the adit level at the Copper Hill mine, Zone II is well-exposed and the non-rotational character of the breccia can be ascertained, because the foliation in the individual quartz diorite fragments still exhibits a common attitude.

Zone III, where present, represents the innermost or central zone of the pipes as shown on the idealized Plate VIII.

PLATE IX

A. Central breccia pipe area in floor of Copper Basin. View west from Copper Basin road.



B. View east across Copper Basin. Late Tertiary(?) rhyolite plug in center.

This zone is characterized by marked rotation and mixing of fragments. The fragments are rounded, sub-rounded and locally angular. Some rounded to sub-rounded fragments have been broken into smaller angular pieces or cut by a network of incipient fractures. In many places the rounded fragments resemble stream boulders and can be described as a "rubble" breccia.

Zone III shows some variations from a circular or elliptical outline in plan. Zone III exhibits sharp contacts with Zone II in some places and is gradational over 10 to 30 feet in other exposures. The vertical shape and extent of this zone could not be determined.

Zone III is not present, or at least not exposed, in many pipes in the district. It is well-developed in the Commercial, Copper Hill and Loma Prieta pipes. In the Copper Hill adit, zones II and III have been faulted together and a direct comparison can be made. Plate VII shows the rounded to sub-rounded fragments of gneissose Precambrian quartz diorite mixed with quartz monzonite fragments of late Cretaceous (?) or early Tertiary (?) age. The Loma Prieta mine was completely flooded in 1952, but Anderson (1945) indicates that fragments of different composition are mixed together. Portions of the main Commercial pipe contain well-mixed, rounded fragments of a variety of rock types.

Associated mineralization

The general nature of mineralization within the pipes was ascertained by studying the surface, accessible adits, and dump material from flooded or caved workings. Unfortunately most of the accessible workings are in the oxidized or partly oxidized zone. Dump material is somewhat misleading since it is mostly waste material and from unknown locations.

Quartz deposition ranged from pervasive silicification to partial replacement of breccia fragments to filling of pre-existing open spaces. Some silicification and replacement quartz is cut by quartz filling interstices between fragments and fractures. However, much structural readjustment took place during mineralization and there was continuous recementing of earlier quartz by later quartz. It is possible that replacement quartz formed in confined areas and the space-filling types formed in through-going trunk channels.

Much of the replacement quartz is a white to gray, dense variety which is commonly associated with orthoclase. Both minerals, together or individually, replace breccia fragments. Some of this replacement material resembles aplite or alaskite. Gilluly (1946, pp. 74-76) describes similar mineralization in the porphyry copper deposit at Ajo, Arizona. The elongate breccia mass about 600 feet east of the Commercial pipe is strongly silicified and the original fragments can only be distinguished locally.

The space-filling quartz is commonly granular to glassy in appearance. Some is coarse-grained and crystals as much as 1 inch in long dimension were observed projecting into vugs between breccia fragments. A few lenticular veins of coarse glassy quartz as much as 10 feet wide are present in and near some of the pipes. The massive glassy quartz locally contains a few isolated feldspar crystals.

In addition to feldspar and quartz, there was minor replacement of fragments by sericite, biotite, and chlorite.

Hydrothermal alteration of the unsilicified country rock within the pipes is obscured in the oxidized zones by much iron-staining and secondary argillic alteration. There is a wide range in intensity of hydrothermal alteration as observed mostly from dump fragments, and no attempt will be made to present a detailed alteration picture. The original mafic minerals are completely bleached out in some specimens and altered to chlorite, serpentine, and biotite in others. Feldspars have undergone varying degrees of sericitization and local argillic alteration. Locally the original textures of the igneous rocks have been completely destroyed but in general the alteration is weak to moderate and the original rock types can be easily identified.

Where fragments are well-mixed there is a difference in the intensity of alteration among adjacent fragments. This is probably due to the original physical and chemical differences of the fragments. The quartz monzonite porphyry and

and quartz latite porphyry fragments appear to be especially resistant to replacement and alteration.

In areas where the quartz is dominantly of the fissure filling type the alteration is less intense and appears to be evenly distributed through the individual fragments.

Alteration of the joint-fracture area included in Zone I is generally weak except along some of the stronger fracture zones. Original biotite is only partially bleached in many places and sericitization of feldspar is not pronounced.

Sulphides, essentially comprising pyrite, chalcopyrite, and molybdenite followed the quartz and, for the most part, deposited in cracks and voids within the quartz. Minor blebs and veinlets of sulphide worked out into the altered igneous rock fragments. The mineralization is remarkably similar to the common porphyry copper types.

The age of minor amounts of brown carbonate is in doubt, but some is definitely post-sulphide.

Structural considerations

The locale of the breccia pipes is within well-jointed and fractured igneous rocks. The magnitude and time of displacement along fractures in the homogenous igneous rocks could not be determined.

It is probable that no single structural control is responsible for the location of the pipes. Many are located at the contact of two or more igneous rock units. Several pipes are situated at the contact between the quartz monzonite and the quartz monzonite porphyry. The Commercial pipe is at the junction of four different igneous rock types (Plate XI).

No major faults were mapped in the vicinity and no alignment of pipes was noted along minor faults. Two sets of fractures are prominent in the Copper Hill and Commercial pipes; one strikes N. 20° - 30° W., and the other N. 20° - 40° E. These structures, for the most part, appear to be post-pipe in age but in part earlier than some of the quartz and sulphides. However, the N. 20° - 40° E. direction is parallel to a regional fault that may have been an important control in the emplacement of the Copper Basin stock rocks. This direction was important in controlling the main trend of the quartz latite dikes and it is probable that the structural adjustment continued. Thus it seems likely that at least one of the fracture sets and possibly the intersection of two sets may have served as the initial loci for some of the pipes. Tongues of breccia locally project out from the pipes along these and other directions (Plate XI). Any pre-pipe controlling faults or joints would have been obliterated within the pipe area by the subsequent processes involved.

The joints and fractures may have controlled, in some places at least, the initial trunk channels of the pipes and undoubtedly influenced the overall permeability adjacent to the trunk channel. Zone I essentially represents this early structural environment and Zone II is an accentuation of these structures to crackle breccia by forces other than tectonic. The nature of the intersections of the joint and fracture systems does not represent an environment that would suggest a tectonic origin for the breccia found in the pipes.

Existing Theories

The origin and classification of steep columnar or tabular bodies of breccia have received much attention in the literature. Publications which review the literature or offer a classification have been written by Butler (1913, pp. 127-129), Emmons (1938, pp. 1-15) and Kuhn (1941, pp. 512-538). Emmons made a fourfold classification based mostly on type of fragments and not on origin.

The origin of most breccia pipes has been explained by the following theories or by modification and/or combinations of them:

(1) Explosion
(2) Friction (tectonic)
(3) Igneous intrusion
(4) Fluid intrusion
(5) Solution and replacement
(6) Mineralization stoping
(7) Shrinkage.

(1) Explosive action, generally thought be be associated with volcanism, is responsible for openings that have been blown out by gas. The opening may be filled with volcanic debris or fragments of country rock. The opening has been called "diatreme" and the filling is known as a "perforation" pipe (Emmons, 1940, p. 224). However, diatreme is often used in the literature to refer to the filling as well as the opening.

The Cresson "blow out" in the Cripple Creek district, Colorado, is a classical example of this type (Lovering, 1950, p. 293). Characteristic features of diatremes in the Hopi Buttes volcanic field, Arizona have been itemized by Hack (1942, pp. 335-372).

Criteria for this type of pipe include upward movement of material, introduction of foreign fragments, some igneous material, and intense fracturing and brecciation.

(2) Friction breccia formed at the intersection of two or more faults or shear zones or at bends in one fault may form columnar pipes of breccia. Commonly this type of pipe is irregular and changes notably as it passes from one wall rock to another. However, fault intersections are important as loci for pipes essentially formed by other agencies. Butler (1913, p. 126) and Kuhn (1941, p. 527) have emphasized fracture and fault intersections as loci for pipes in the San Francisco area, Utah, and Copper Creek, Arizona, respectively.

(3) The direct formation of breccia columns or dikes by the physical force of intrusion has been noted by many authors. Lovering (1942, p. 8) states:

> "An intrusive push at a late stage in the solidification of a magma may cause the fracturing of a stock along lenticular or chimney-like zones that usually have their longest dimension parallel to the original platy structure of the intrusion. In such masses the small opening produced by intensive brecciation may be subsequently enlarged by reactive mineralizing solutions which dissolve some of the rock adjacent to the individual fractures--the first step in mineralization stoping as suggested by Augustus Locke."

Lovering (1949, p. 12) gives an example of pebble dike formation by this method in the East Tintic district, Utah.

> "A large number of the pebble dikes is believed to represent material riding on top of monzonite or dragged along the edge of viscous monzonite bodies, but some pebble dikes are probably explosive breccia."

(4) Fluid intrusion has been advocated as another means of pipe or dike formation. This theory has much in common with explosion breccia but is apparently more confined and has characteristic intrusive phenomena. The fluid involved is assumed to be gas or liquid of magmatic derivation but does not involve magma.

Marsell (1932, p. 76) suggested for a pipe-like mass in East Traverse Range, Utah, that

> "...the fragments have been lifted to their present state by a viscous magmatic differentiate."

Farmin (1934, p. 370) advocated the following for the pebble dikes at Tintic, Utah:

> "...fragments were broken from the underlying rocks by magma, or by fluids ejected from the magma during volcanism and were forced upward into rocks above by a relatively thick mud."

(5) Corrosion by ascending solutions has been advocated by Butler, (1913, pp. 126-129) for pipes in the San Francisco region, Utah. Butler's discussion of the Cactus ore body explains the theory.

> "The rock has been brecciated apparently by slight movement, as no considerable fault can be traced from the ore zone. Solutions passing through this breccia zone have greatly corroded the rock, so that in places the fragments have the appearance of rounded boulders. In this manner the amount of open space must have greatly increased. Later this space was largely filled by ore and gangue minerals."

Butler further suggests that the solutions were relatively confined and the dissolving action strong.

Kuhn (1941, p. 527) applied essentially the same theory to the pipes in the Copper Creek, Arizona, area but emphasized simultaneous replacement.

> "These solutions caused replacement of the rock adjacent to the joints and fractures by chlorite, sericite, quartz, feldspar, and tourmaline, which gradually destroyed the rock, until in places, it was entirely replaced by secondary minerals."

However, Kuhn (1941, p. 528) does mention that in places

> "...the dissolving action was more intense than deposition, resulting in open or incompletely cemented breccia."

(6) Locke (1926, pp. 431-453) proposed the theory of mineralization stoping to account for the formation of certain pipe deposits. This theory is analogous to the block-caving method of mining. Locke (p. 431) states that

> "...removal of rock along trunk channels by rising solutions during an early stage of their activity, collapse and brecciation of the rock thus left unsupported, and deposition of ore and gangue minerals in the brecciated mass."

A definite prerequisite for this theory is proof that there was downward movement of the breccia mass.

(7) Hulin (1948, pp. 47-49) suggests the estimated 10 percent volume shrinkage on crystallization is responsible for much fracturing and brecciation in certain stocks or chonoliths. He states:

> "The result would be unsystematized fracturing and shattering with attendant volume increase, structural features so characteristic of the porphyry copper ores...

> In the absence of such autobrecciation the subsidiary ground might move downward within the limits of an encircling, crudely cylindrical fault surface, or within a nest of such surfaces."

This theory would probably not account for numerous breccia pipes widely distributed in more than one rock type.

Origin of Copper Basin Pipes

General statement

In considering the origin of the roughly circular to elliptical columns of breccia in the Copper Basin mining district it should be emphasized that other types of breccia are present. All of the units of the Copper Basin stock rocks were injected into their present position and contact or intrusive breccia is present in many places. Since several pipes formed at intrusive contacts, some of the original brecciation may have been inherited from previous intrusive phenomena, but this is not thought to be a critical factor in the origin of the pipes in general.

Fracturing and brecciation associated with faults was observed in many places. Where mineralized these breccia zones are apt to be linear and highly irregular. However, faulting is thought to have served as original controlling loci for at least some of the pipes and minor fault breccia may have been present locally.

Summary of data

The literature indicates that the origin of many breccia pipes is a controversial subject. The observations of the pipes in Copper Basin were limited by inaccessible workings and the fact that none of the pipes have been extensively developed in depth. Thus it was thought wise to present the available factual material and then the interpretations.

1. The pipes are spatially related to the Copper Basin stock rocks. Further, the pipes appear to be spatially related to the postulated orifice or funnel-shaped root of the stock.

2. The pipes formed after solidification of all the Copper Basin stock rocks exposed at the surface and prior to emplacement of the late Tertiary (?) rhyolite.

3. The pipes are roughly circular or elliptical in plan. The depth extension is only known over a maximum distance of 400 feet, but they appear to be near-vertical columnar pipes.

4. Certain pipes formed at the contact of two or more igneous rocks. Others formed within one uniform igneous rock.

5. No major faults were observed in the vicinity of pipes, but pronounced joint systems and minor faults are abundant.

6. No arcuate structures were found in or near the pipes.

7. The fragments range from about 1 inch to 10 feet in diameter and average about 2-12 inches.

8. Fragments in zone II are angular and subangular. Fragments in zone III are angular to well-rounded (Plate VIII).

9. Movement of fragments in zone II has been non-rotational and has resulted in little or no mixing. Movement in zone III has been rotational and the fragments are thoroughly mixed in places.

10. No definite evidence was found to prove whether the fragments moved up or down within the pipes.

11. The fragments in general do not have an igneous matrix.

12. In certain pipes or portion of pipes quartz, orthoclase, and, locally, sericite, biotite, and chlorite replace the borders of fragments. Pervasive silicification is present in some pipes.

13. More commonly quartz deposited in interstices between fragments. Quartz crystals locally formed in vugs in the inter-fragment spaces. This deposition in zone III followed the rotation and mixing of fragments.

14. In general pyrite, chalcopyrite, and molybdenite were later than the quartz and filled fractures in it. Minor amounts of sulphide deposited in the fractures and inter-granular spaces within the fragments.

15. Minor fracturing and faulting occurred after some quartz deposition and prior to introduction of sulphides.

16. There is a wide variation in intensity of hydrothermal alteration of fragments. Comparatively fresh fragments of one rock type may be present near strongly altered fragments of another rock type. Alteration products in the hypogene zone include sericite, minor clay minerals, chlorite, and biotite. Alteration is rarely intense enough to obscure the original rock identity.

Interpretation of origin

1. Breccia pipe formation is associated with the late magmatic stage of the Copper Basin stock. Late magmatic fluids gradually concentrated around the root area of the composite stock after the solidification of the roof portion and formation of a joint and fracture system.

2. Positive evidence as to the exact state of the early fluids or to the pressures involved is lacking. However, the fluids gradually collected in several individual structural chambers in the vicinity of the root of the composite stock.

3. The fluids moved upwards along lines of least resistance. In many places this was the steeply dipping contact of two or more igneous rocks. In other places it was the intersection of joint or fracture systems.

4. Once the fluids from any individual chamber reached the surface or near-surface area, a trunk channel formed and the pressure gradient directed most of the fluid within the confined chamber of this outlet.

5. Whether or not any explosive action resulted when these fluids first penetrated the low pressure zone near the surface is conjectural. There is no positive evidence to support explosive action at the elevation of exposure of the pipes at present. The nonrotational aspect of zone II and the limitation of zone III to only three pipes suggests that explosive action was not important at the elevation of exposure.

6. Early fluids moving up trunk channels penetrated the adjoining walls along previous joint and fracture surfaces. Some of the fluids replaced the rock adjacent to the joint and fracture surfaces with quartz and orthoclase and formed a "replacement" breccia. It is probable that pipes formed entirely of "replacement" breccia did not reach the surface at the time of formation.

7. Some fluid, possibly in more open trunk channels, removed much material. The fragments in these channels were rounded, rotated, and mixed together. The process by which the material was removed is open to question. Evidence for corrosive action is not commonly apparent. It is suggested that incipient alteration of the fragments loosened the mineral grains

at the borders. This loosening effect was accentuated by contemporaneous and subsequent movement and attrition of the fragments. The fluids carried the loosened material out.

8. In this stage of development most of the movement of the breccia mass was probably downward as the whole pipe slumped from continual removal of material. Zone III continued to work outward from the trunk channel into zone II. After the pipe was well-developed, portions of zone II probably tended to slump in toward zone III; thus forming more open space in the former zone.

9. Following the formation of the open mass of breccia in zones II and III, quartz deposited in the open spaces and also in the joint and fractures in zone I. During and after deposition of this quartz, structural adjustment fractured all of the early cementing and replacement minerals. Then sulphides deposited in these fractures, showing a strong preference for those in quartz.

10. Faulting and fracturing continued after the sulphide stage and several pipes have been displaced as much as 200 feet.

ORE DEPOSITS

General Statement

The ore deposits of the Copper Basin mining district have been divided into three age groups based on evidence found in their relationships to igneous rocks, structures, mineralogy, and similarity to deposits of known age. Lindgren (1926, p. 310) classified the ore deposits in the nearby Jerome and Bradshaw Mountains Quadrangles as Precambrian and Mesozoic (?) or early Tertiary (?) in age. This classification in modified form is extended to the Copper Basin mining district, but a late Tertiary (?) and Quaternary heading is added to include minor mercury and placer deposits. The proposed age classification used is Precambrian, Laramide (?), late Tertiary (?) and Quaternary.

Precambrian deposits comprise minor gold and copper ores associated with tourmaline-quartz veins.

Laramide deposits, which have yielded the bulk of the district production, include copper and molybdenum associated with breccia pipes and zinc-lead-silver fissure-filling and replacement veins. Minor amounts of gold are associated with the above deposits.

Late Tertiary (?) and Quaternary deposits include mercury prospects associated with rhyolite, and gold placers.

As in many old mining districts which have been sustained by sporadic production and development over 60 to 70 years, many of the workings were either flooded or caved and reliable information was not available. However, an attempt was made to place the deposits in a general district pattern.

History and Production

Exactly when ore was discovered in the district in unknown but according to Lindgren (1926, pp. 2-3) gold-seeking placer miners from California invaded the Bradshaw Mountains about 1863 and lode mining began about 1875. Blake (1889, pp. 479-85) discusses the copper-cemented terrace gravels along Copper Basin Wash. The Copper Basin mining district was officially recognized in about 1890.

Two active periods of lode mining in the district were from 1914 to 1919 and 1942 to 1950. Recorded production from 1936 to 1951, given in Table II, totals approximately $1,000,000. Earlier production, including placer gold, is estimated from comments and tonnage figures in Mineral Resource volumes as another $1,000,000, giving a grand total of about $2,000,000.

Unfortunately, Elsing and Heineman (1936) omitted the Copper Basin lode production in their summary of Arizona metal production. They give placer production to 1933 as $50,000.

Copper ranks first in production and zinc, lead, silver, and gold follow in order listed.

	Mines producing		Tons	Gold (ounces)	Silver (pounds)	Copper (pounds)	Lead (pounds)	Zinc (pounds)	Total Value
	Lode	Placer							
1936	1	120	6	270	46				9,471
1937	4	77	313	166	266				6,009
1938	8	22	2,073	207	3,038	25,686	211,525	159,123	35,456
1939	5	6	73	126	212	2,904			4,856
1940	5	8	74	86	111	4,053	7,600		3,927
1941	2	9	2	49	7				1,720
1942	5	7	9,425	123	450	456,700	1,000	66,000	66,091
1943	5		11,634	1	343	530,900	1,160	27,000	73,082
1944	2		15,638	8	959	670,410	1,300	30,500	95,047
1945	2		12,515	28	2,364	462,200	41,500	650,000	143,377
1946	2		10,481	8	1,240	459,500	23,400	307,000	115,726
1947	2		15,096	5	822	754,000	3,300	56,200	166,534
1948	4	3	13,860	43	854	611,000	29,400	19,700	142,748
1949	5		3,922	30	389	192,600	15,600	17,900	44,029
1950	3		4,799	7	431	285,800	6,600	20,900	63,940
1951	1	1	56	5	95	400	11,300	8,500	3,860
Totals			99,967	1,162	11,627	4,466,153	353,685	1,362,823	$975,873

Table II: Recorded metal production - Copper Basin mining district, Arizona (Minerals Yearbooks).

Placer operations have probably been carried on since the discovery of the district but the only active interval recorded is from 1929 to 1937.

Relation to Igneous Rocks and Zoning

The tourmaline-quartz veins are found in all of the Precambrian rock units and are absent in the later rock units. These veins are identical to tourmaline-quartz veins described by Lindgren (1926, p. 103) in the Cherry Creek district, 30 miles to the east, which do not penetrate overlying Paleozoic rocks. Although the veins are present in all of the Precambrian rocks there is a suggestive spatial relation with the Precambrian granodiorite porphyry unit. Several veins are present near the contacts of this unit in the Finch

Wash area. However, some tourmaline-quartz veins are present in the later granodiorite unit. No evidence of zoning was noted in these veins.

Deposits, designated as Laramide (?), are later than all of the Copper Basin stock units and younger than the late Tertiary (?) rhyolite wherever evidence is available. A definite spatial relation exists between the Laramide (?) ore deposits and the Copper Basin stock rocks and a genetic relation, in reference to a common source, is inferred.

Zoning is well-displayed in relation to the Copper Basin stock. The copper-molybdenum deposits are found in breccia pipes located directly above the restricted orifice or nozzle through which the different Copper Basin magmas were injected. The zinc-lead-silver deposits form an elongate aureole around the copper-molybdenum center. The most productive zinc-lead-silver deposits are concentrated along the west side of the district but prospects having similar minerals are found concentrically around the other sides of the Copper Basin stock.

Minor amounts of mercury minerals are associated with hot spring deposits in late Tertiary (?) rhyolite breccia zones in the southwest part of the district.

Structural Controls

Most of the Precambrian tourmaline-quartz veins are controlled by faults striking N. 60° - 75° W., or N. 55° - 75° E. The detailed control of the shoots within the veins was not determined.

General structural control of Laramide (?) deposits is found in a combination of the structures which controlled the intrusion of Copper Basin stock rocks with some that were formed by the intrusive force or by later forces. Intrusive contacts appear to have been particularly favorable for determining the route of ore solutions. The structural control of breccia pipe deposits containing copper and molybdenum has been discussed in detail under a separate heading.

The productive zinc-lead-silver mines along the west side of the district were controlled by the Boston fault zone and the Navy thrust. In detail the shoots along this belt were formed at fault intersections, intrusive contacts, structural terraces formed by flattening of dip in thrust faults, and in areas of drag folds along a fault in which an incompetent bed was deformed between two competent bands. In other parts of the district veins occupy fractures and faults showing a variety of strikes and dips (Plate X). Mine development has been insufficient to determine detailed controls.

Late Tertiary (?) mercury deposits are associated with numerous rhyolite dike and dike breccias which commonly strike north to N. 70° W.

Mineralogy

Precambrian ore deposits

Sulphide minerals observed in the Precambrian tourmaline-quartz veins comprise pyrite, chalcopyrite, and minor amounts of dark brown sphalerite. Pyrite occurs as dark bronze-colored, cubic crystals which are commonly striated. Chalcopyrite occurs as small irregular grains and blebs. Small high grade shipments of gold ore from the district have come from portions of Precambrian veins which contain massive streaks of bronze-colored pyrite.

Gangue minerals are quartz, tourmaline, carbonate, chlorite, and included country rock. The quartz is generally massive granulated milky forms. Some crystals as much as 1 inch long are locally present in most of the veins. Black to dark green tourmaline occurs as irregular splotches intergrown with quartz. Prismatic tourmaline crystals can be observed near the edges of the splotches. Dark green chlorite is present near the tourmaline quartz veins and is locally included within the vein. Brown carbonate has been replaced by milky quartz in some veins and appears to be later than quartz in other veins. Massive streaks of magnetite and specular hematite as much as 4 inches thick were found next to a tourmaline-quartz vein about a half mile west of the U. S. Navy mine.

The zone of oxidation extends to a depth of about 50 feet. Pyrite kernels in limonite gossan were observed in outcrops. The massive pyrite veins have weathered to a cellular and massive varnish-type limonite gossan.

Laramide (?) deposits

Hypogene sulphide mineralization associated with the copper-molybdenum zone in the breccia pipe area comprises pyrite, chalcopyrite, bornite and molybdenite. This mineral association is typical of the Laramide "porphyry copper" deposits and has not been described from deposits of known Precambrian age in the Southwest.

Pyrite was the first sulphide introduced in the deposit and is everywhere abundant. It occurs in cubic and pyritehedral forms, and as disseminated grains. Light yellow pyrite is characteristic of the Laramide (?) deposits in contrast to the darker bronze-colored pyrite in Precambrian veins. The pyrite crystals range from minute grains to 1 inch cubes.

Chalcopyrite veins cut pyrite in some specimens but appear in part, to have been introduced at the same time. Chalcopyrite occurs as subhedral crystals and discrete grains commonly intermixed with pyrite.

Bornite was observed as discrete grains and blebs, but its relation to other sulphides was not determined.

Short prismatic crystals and tabular scales of molybdenite are present in all of the productive pipes. Molybdenite veins transect pyrite and chalcopyrite masses. In many parts of the pipes the above three sulphides occur together but not uncommonly molybdenite occupies later fractures not associated with the earlier sulphides. The yellow oxide, molybdite, is common near the surface.

Gangue minerals have been discussed in the origin of breccia pipes. In summary the gangue includes replacement quartz and potash feldspar, alteration products of pre-existing igneous minerals, vein quartz and carbonate.

Most of the copper production in the district has been from the oxidized zone. Since the stoped areas are mostly inaccessible the abundance and relation of minerals can only be suggested from dump fragments. Oxidized copper minerals observed include malachite, azurite, chrysocolla, cuprite, and native copper. Fragments showing chalcocite replacing chalcopyrite and pyrite are abundant on dumps in the main breccia pipe area. Sooty chalcocite was also observed in the same area. Limonite and jarosite are mixed with the oxidized copper minerals.

The zinc-lead-silver deposits surrounding the central copper-molybdenum zone exhibit a simple and rather uniform group of minerals.

Galena is present in the veins in crystals ranging from minute specs to cubes 2 inches in diameter. Oxidation products include local cerussite and anglesite, but galena was found in places on the surface. Sphalerite is generally light to medium brown but darker varieties are not uncommon. It occurs as massive granular replacement ore and as coarse-grained aggregates containing crystals as much as 1 inch in long dimension. Oxidation products of primary zinc sulphide comprise smithsonite and calamine.

Silver minerals were not observed and it is probable that most of the silver values are present in galena.

Pyrite is present in the same forms as in the copper zone but the ratio to other sulphides is much smaller. Pyrite cubes 2 inches square were found on the Mint mine dump. Cellular limonite, hematite and jarosite gossans crop out on surface.

Gangue minerals include quartz, carbonates, and altered country rocks. Other than strong silicification in some vein zones, hydrothermal alteration is relatively weak. Sericite, chlorite and argillic alteration minerals are sparingly present.

Late Tertiary (?) and Quaternary deposits

Cinnabar has been reported from several prospects in the southwest corner of the map area. It was only tentatively identified in a few specimens in which it was mixed with pyrite, hematite, and limonite. Natural amalgam has been reported in placers from streams that drain this area.

Precambrian Deposits

Gold Star mine and extension

The Gold Star mine is located in the northwest part of the map area 3 miles from Skull Valley on the Boston-Arizona mine road (Plate X). Minerals Yearbook, 1938, states that gold ore of smelting grade was shipped from the Gold Star mine.

Caved mine workings, about 200 feet west of the road, consist of a vertical shaft, inclined shaft, and adit.

The vein strikes N. 50° - 60° W. and dips 30° - 40° NE. An 18 inch thick vein composed of sheared chloritic material, milky-glassy quartz, and black tourmaline is exposed at the portal of the caved adit. A small quantity of bronze-colored pyrite was examined in fragments taken from the dump. The country rock is foliated amphibolite which has been intruded by numerous basic dikes.

The vein can be traced about 1000 feet to the southeast, at which point a northerly striking fault offsets an east segment about 500 feet north. This segment strikes N. 60° W. and dips 50° NE. An inclined shaft, caved at the 15 foot level, follows the dip of the vein. A 2-foot thick vein of tourmaline and milky quartz is exposed in a caved adit about 200 feet, N. 65° W. from the shaft. Minor amounts of bronze-colored pyrite was found on the shaft dump. The country rock here is a foliated and altered Precambrian quartz diorite.

The above described vein can be traced 2000 feet east to another inclined shaft. Here the vein strikes N. 75° W., and dips 40° - 50° NE. Tourmaline and quartz appear to have replaced brown carbonates as observed in fragments from the dump. Bronze colored pyrite is sparingly present.

Finch vein

A tourmaline-quartz vein, ranging from 6 inches to 6 feet wide, was traced from the bottom of Finch Wash, more or less continuously for 4000 feet west to a dump about 3000 feet east of the Boston-Arizona mine (Plate X). The country rock is Precambrian granodiorite porphyry and amphibolite. The vein strikes N. 65° - and 80° E. and dips 55° - 75° NW.

The vein near the bottom of Finch Wash has been partially developed by what is generally known as the workings of the Finch mine. The northerly-striking Finch fault which follows Finch Wash in the area has offset the vein a lateral distance of about 2000 feet; the west wall moved north relative to the east wall (Plate X).

The south segment strikes N. 70° E. and is exposed for about 200 feet from Finch Wash. The vein ranges from 2 to 5 feet in width here and contains some cellular limonite gossan and minor amounts of oxidized copper minerals. Workings consist of several shallow pits.

The north segment is developed by an adit bearing N. 20°W. from the bottom of the wash. The adit extends 75 feet to a winze which couldn't be crossed. The adit continues at least another 75 feet. Glassy quartz containing sparse tourmaline and disseminated cubic pyrite was noted on the dump. About 1500 feet, S. 65° W. from the adit portal is a shaft inclined 75°NW. on the dip of the vein. In 1952 it was about 60 feet to water and no stopes were visible. However, two small shipments of high grade gold reportedly came from this shaft and an old aerial tram to an ore bin at the bottom of the wash suggests some production. A strong shear at the collar of the shaft includes 3 to 4 inch lenses of glassy quartz over a width of about 18 inches.

The west end of this vein has been exposed in an adit, the dump of which is visible from the Boston-Arizona mine. The adit was driven a paced distance of 475 feet, N. 70° - 80° E. on a strong shear zone up to 6 feet wide. The shear zone contains irregular quartz lenses, as much as 3 feet wide, in the first 150 feet from the portal. Quartz veins up to 12 inches wide were observed elsewhere in the workings and are prominent near the face. No sulphides were found underground, but fine-grained pyrite in glassy quartz was observed on the dump. One fragment containing sphalerite and chalcopyrite was also found on the dump.

Plymouth mine

The Plymouth mine is located on the east side of Finch Wash about one mile north of the Copper Basin road (Plate X).

Small shipments of gold-copper ore are reported by Minerals Yearbook from the Plymouth mine in 1937 and 1939.

The workings expose a vein striking N. 40° - 60° W., and dipping 70° - 80° NE. The vein is in Precambrian granodiorite porphyry near its contact with Precambrian amphibolite. The late Cretacious (?) or early Tertiary (?) quartz latite porphyry dike, which extends from Copper Basin to the Boston-Arizona mine, crops out 200 feet southwest of the Plymouth vein and is parallel to it. The dike crosses the Finch fault without offset but the Plymouth vein ends at the fault (Plate X).

The workings consist of a shaft on the vein inclined 72° NE., and an adit, driven into the vein from a point 75 feet west of the shaft. A vein of varnish-type gossan and glassy quartz, 6-8 inches wide, is exposed in the shaft near the collar. A stope caved to surface, extends from the shaft 30 feet to the northwest along the vein. Coarse dark bronze pyrite in cubes up to 1 inch in diameter is present on the dump. Some massive pyrite was observed and the gossan indicates an original massive pyrite vein. Small amounts of copper minerals were also observed on the dump. No tourmaline was found, but the mineralization indicates a Precambrian massive pyrite vein, probably containing erratic gold values.

McNary mine

The McNary mine is located on the west side of the district about a mile southwest of the U.S. Navy mine (Plate X). A house built of white rhyolite blocks near the workings serves as a landmark.

Small shipments of gold ore of smelting grade from the McNary mine are reported in Minerals Yearbook for the years 1938-1940. Two small open stopes were observed in the workings.

The mine is in Precambrian quartz diorite near the south contacts of the small body of quartz monzonite related to the Copper Basin stock. The mine explored a Precambrian tourmaline quartz vein striking N. 55° - 65° E. and dipping from 65° SE. to 80° NW. A shear zone striking N. 45° W. has offset the vein a horizontal distance of 175 feet; the northeast vein segment was shifted northwest relative to the southwest segment.

The mine has been developed by an adit which bears N. 40° E. from the portal for 150 feet to a junction where an east crosscut developed the southwest vein segment for a strike length of 115 feet. A partially filled stope, 50 feet along the strike and as much as 60 feet above the level, exploited the upper part of the tourmaline-quartz vein containing dark bronze colored pyrite and minor amounts of chalcopyrite. The original vein width in the stope is unknown but remaining extensions do not exceed 8 inches in thickness.

Another branch of the adit level extends north from the junction, crosses the N. 45° W. shear, and intersects the northeast vein-segment at 195 feet. From the point of intersection the level extends 165 feet, N. 65° E, along the vein to a raise. The raise connects at 25 feet with a sublevel which follows the vein for about 150 feet to a vertical shaft which extends to the surface. A small stope 4 feet wide, 30 feet long, and 20 feet high, extends up from the sublevel.

The vein zone in the northeast segment locally attains a width of 4 feet but sulphide portions generally do not exceed 4 inches in width.

Flower Gold mine

The mine is located near the east contact of the late Tertiary (?) rhyolite tuff unit and about 1000 feet north of the Copper Basin road (Plate X).

Minerals Yearbook (1939) records a small lot of rich gold ore from the Flower Gold mine.

The mine developed a milky quartz vein striking N. 70°- 80° W., and dipping 70° - 80° NE. The host rock is Precambrian quartz diorite.

A shaft, inclined 75° north, was not accessible in 1952. An adit, 100 feet east of the shaft, was driven 20 feet westward on a shear zone about 18 inches wide and containing irregular lenses of milky quartz. A small pit about 300 feet south of the shaft exposed minor amounts of oxidized copper minerals including cuprite.

Other prospects

The Roosevelt mine is located in the northwest part of the area about one mile north of the Gold Star mine (Plate X). The mine has been developed in a 1-4 foot vein containing milky quartz. The vein strikes N. 45° E. and dips 70° - 80° SE. A shaft has been sunk on the vein for about 50 feet.

The shaft is lagged tight but there is evidence of some stoped ground down to 35 feet. Dark bronze-colored pyrite in milky quartz was observed on the dump.

Some oxidized copper has been mined from workings located in the northwest corner of the mapped area. Two caved shafts were observed on a vein striking N. 10° - 45° E. and dipping steeply northwest. A vein 30 inches wide and containing cellular gossan is exposed at the collar of the northernmost shaft.

Laramide (?) Deposits

Commercial mine

The Commercial mine, owned by Phelps Dodge Corporation, consists of 21 patented claims in the center of the district (Plate X). This mine has furnished the bulk of the copper production from the district. The mine was inactive in 1952 and most of the workings were inaccessible.

The early history of the mine development could not be learned. The oxidized copper-cemented terrace gravels mentioned by Blake (1889, p. 479-485) were probably the first ores mined from the property. Development was underway in 1912 and the first period of production of high silica copper ores was from 1914-1919. Mineral Resource volumes give this production as 60,553 tons, but figures are lacking for 1915-1916. The next period of production was from 1942-50 when F.D.Schemmer, lessee, operated the mine. Minerals Yearbook volumes record this production as 92,218 tons of high silica copper ores. The mine closed in May, 1950 when the Phelps Dodge smelter at Clarkdale, Arizona, ceased operations.

The main producing area around the Commercial and Smelter pipes is developed by shafts and adits (Plate XI). Minerals Resource volume (1914) notes a 600 foot vertical shaft with numerous drifts and openings. This shaft is located on the north side of the Smelter pipe. An adit skirts the southwest side of Smelter Hill and continues into the main stope area under Commercial Hill. Another main adit extends from the southwest side of the Commercial pipe into the main stope area and connects with the other adit. Several more adits and shallow shafts are present on these two hills and on other mineralized pipes.

Most of the copper production has come from what is here designated as the Commercial pipe (Plate XI). This pipe is roughly 600 feet in diameter at the surface. It occurs at the junction of several igneous rock types as shown on Plate XI.

The pipe is composed of angular and rounded fragments of the adjoining igneous rocks ranging from 1 inch to 10 feet in long dimension. Some of the fragments are intrusive breccia but most appear to be formed by replacement or attrition. The fragments are cemented by quartz or replacement minerals including quartz and orthoclase. After the pipe formed and some of the quartz had deposited, it was fractured by N. 20°- 30° W. and N. 20° - 30°E. striking faults. The fractures were filled with quartz which was subsequently fractured. The sulphides, pyrite, chalcopyrite and molybdenite, for the most part, filled these later fractures in the quartz. Barren portions of the pipe appear to be the unfractured areas.

A strong N. 20° W. striking vein, which extends through the center of the pipe, was stoped from the surface in the early days. Remnants of the old stope indicate it was from 2 to 4 feet wide. This fault was a main feeder for the ore solutions at depth.

The pipe has been oxidized from the surface down to the floor of the present stopes at the main adit level elevation, a distance of about 260 feet. The upper 100 feet, more or less, has been leached and is highly silicified. As seen in ore fragments from the dumps the mineable ore was composed of malachite, azurite, chrysocolla, cuprite, native copper, sooty chalcocite, and some pyrite chalcopyrite and molybdenite. Undoubtedly other copper minerals were present. The gangue was highly siliceous and contained quartz, orthoclase and altered country rock. Important in the formation of mineable oxidized ore was thorough post-sulphide shattering of the pipe to increase permeability for action of surface waters. Unfractured quartz in road cuts still contains primary sulphides.

The elongate Smelter pipe east of the Commercial pipe apparently has produced little ore (Plate XI). A north-striking vein bordering the west side of the pipe was stoped for an unknown distance. The elongate breccia mass formed at the contact of the quartz monzonite and quartz monzonite porphyry units. The entire mass is strongly silicified at the surface. In some areas ghost fragments of igneous rocks can be observed but in many places pervasive silicification has obscured early textures and structures. This competent silicified pipe resisted fracturing, and from surface exposures does not appear to have been well mineralized by sulphides. However, strong oxidized copper showings were observed in scattered exposures along the east contact of the pipe (Plate XI).

Several other pipes have been explored by shallow workings but the nature of the mineralization and structural history was difficult to ascertain.

Near the Smelter adit and north in the Aztec workings, oxidized copper minerals cementing terrace gravels have been mined (Plate XI). The richest ore occupied the first 2 to 4 feet of gravels above the igneous bedrock. The copper solutions, probably originating from oxidation of copper minerals in the Smelter and Commercial pipes moved down along the bedrock surface. The ore minerals occur more as a coating on the fragments than a replacement of cement between the terrace gravels.

Loma Prieta Mine

The Loma Prieta mine is located on the east side of Copper Basin Wash about 700 feet north of the Copper Basin road (Plates X and XI). This mine exploits a breccia pipe characterized by a lack of surface expression so common in most of the other pipes. The pipe is located on a bench covered by as much as 25 feet of terrace gravels. Bedrock exposures are scarce except along the creek bottoms.

The pipe formed in quartz monzonite, the main unit of the Copper Basin stock. A quartz latite porphyry is exposed on the east side of the pipe and breccia fragments of this rock were observed on the dump. A late Tertiary (?) rhyolite dike is partially exposed about 300 feet southwest of the main shaft.

The main workings were completely flooded in 1952. The following summary by Anderson (1945) gives an excellent description of the mine:

> "The development work, done in 1916-1918, consists of a shaft 414 feet deep connected to 1170 feet of drifts on 4 levels. Two or three cars of copper sulphide ore were shipped during this period...The ore consists of brecciated quartz diorite cemented by quartz veins carrying pyrite, chalcopyrite, and locally, molybdenite. The form of the deposit is a vertical pipe of mineralized breccia having a cross-sectional area at the 400 level of 60,000 or more square feet with a cut-off grade at 0.45% Cu. The shaft reveals a 350 foot vertical extent of mineralized rock. Estimated reserves are 1,750,000 tons of indicated ore, with a grade of 0.85-0.9% Cu., and 0.10-0.15% MoS_2"

Copper Hill mine

The Copper Hill mine, owned by Fred Gibbs of Prescott, Arizona, has explored a breccia pipe on the west side of Copper Basin (Plate X). The surface expression of the pipe is a low red hill having about 60 feet of relief.

The only production record is a note in the Minerals Resource volume to the effect that oxidized surface ore was shipped in 1915. A small stope in the adit level may indicate another small shipment.

Mine workings include a vertical shaft located west of the pipe and near the Copper Basin road (Plate XI). Levels were driven east into the breccia pipe from 130 and 330 foot stations in the shaft. The 130-foot level includes about 550 feet of drift and the 330-foot level includes about 230 feet (Gibbs, 1952). These workings were inaccessible in 1952. An adit extends in a northerly direction from the south base of the hill for about 380 feet.

In 1943 a government sponsored drilling project completed 11 diamond drill holes, totalling 1475 feet.

The surface exposure of the pipe is Precambrian quartz diorite, but the contact with the late Cretaceous (?) or early Tertiary (?) quartz monzonite is about 300 feet south (Plate XI). Drill core from the 330 level indicates that quartz monzonite underlies the now-exposed portion of the pipe. The pipe is roughly 300 feet in diameter but has been distorted by post-mineral faulting. The prominent fault systems in the adit and on surface trend N. 10° - 30° W., N. - N. 10° E., and N. 70° - 80° W. These three structures contain coarse glassy quartz veins, as much as 10 feet wide, exposed at the surface. There has been much post-mineral movement on most of these faults but some representatives of all three sets are veined by quartz and sulphides.

The adit level was driven partly along a strong N. 10°-20° W. striking fault which includes up to 3 feet of gouge. This fault displaces a late Tertiary (?) rhyolite dike on the surface a horizontal distance of about 100 feet. However, sulphide mineralization appears to be concentrated near this fault. The west wall of the fault contains rounded fragments of quartz monzonite and Precambrian quartz diorite (Plate VII). In the east wall and crosscut is exposed non-rotated fragments of quartz diorite. Although the quartz monzonite fragments suggest that they have been moved upward, it is more likely that a tongue of quartz monzonite projected up from the underlying mass or the west wall moved upward and represents ground near the contact of the two rock types (Plate X, Section B). A fault exposed in the open cuts at the surface strikes N-N. 10° E. and the surface bounds the west side of the pipe. Sulphides are concentrated along this structure. It is apparent that the above mentioned two faults may have served as feeders and the ore solutions spread out into the breccia on one or both sides of the structures.

The breccia fragments are cemented by glassy quartz which was subsequently fractured, and pyrite, chalcopyrite, and molybdenite deposited in the fractures. The quartz monzonite fragments are altered to clay and sericite. The quartz-diorite is less altered and still exhibits mafic minerals which include hydrothermal biotite after hornblende.

Boston-Arizona mine

The mine is located in the northwest part of the area, about 5 miles northeast of the railroad station at Skull Valley (Plate X).

The Boston-Arizona mine is owned by Mrs. E. O. Weston of Prescott, Arizona, but has been operated by lessees over a period of years. The mine was first developed from 1926 to 1929, but no production is recorded for this period. Data from Minerals Yearbooks indicate that 4,915 tons of zinc ore were shipped from 1942 to 1950 by lessees. This ore reportedly averaged about 19 percent zinc, 1 percent lead, 0.3 percent copper, 1 ounce silver, and 0.01 ounce gold. In 1952 McFarlane and Hullinger of Tooele, Utah, were actively developing the mine, and the workings consisted of one shaft, two winzes, one adit level, and 4 underground levels, totalling 2700 feet as shown on Plate XII). The only inaccessible areas in 1952 were part of the main shaft from the surface and an unknown extension of the 96-foot level beyond the cave at the north end of the drift (Plate XII).

The mine openings explore a segment of the composite Boston fault zone previously described. Surface exposures of the fault zone are scarce in the mine vicinity, but it has a general strike of N. 25° W. A quartz latite porphyry dike, one of the Copper Basin stock rocks, was traced continuously from Copper Basin to a point where it intersects the Boston fault zone, about 700 feet north of the main shaft. The dike is altered and mineralized by sulphides; thus indicating that the Boston-Arizona ore deposit is in all probability, Laramide (?) in age. Post-sulphide faulting within the Boston zone has displaced the dike a horizontal distance of 1500 feet; the west side has been shifted south (Plate X). Where the dike intersects the Boston zone 700 feet north of the shaft there is a strong N. 70° - 80° W. shear zone or fracture cleavage direction beyond which the vein could not be found. Cellular limonite gossan was observed in pits and a short adit about 3000 feet south of the shaft.

The country rock is the Precambrian metasediment unit composed of foliated or bedded, light grey (a) to green tufface-ous sediments intercalated with generally conformable dense basic bands. The origin of the basic bands is in doubt but they could be thin basic flows, stills, or crystal tuffs. Some discordant masses are obviously basic dikes. In zones of shear and hydrothermal alteration the basic bands have been changed to coarse chlorite and mica. This sequence has a general strike of N. 20° - 30° E. and dips 50° - 70° NW, but drag associated with the Boston fault zone disturbed the general attitude as observed in mine workings.

The main structure or shear zone is best displayed on the 96-foot level (Plate XII). In general the zone ranges from 25 to 75 feet wide and trends N. 20° - 30° W. There are numerous converging and diverging, curving fault planes, but commonly two major shear planes bound the zone. Much post-mineral faulting has been superimposed on the structures. The west-bounding fault is characterized by strong post-mineral gouge and this structure is probably responsible for the 1500-foot displacement of the quartz latite porphyry dike at the surface. Most of the faults dip steeply west but the main pre-mineral zone is nearly vertical. Important minor structural features are drag folds, curved bedding-foliation plane faults, and general fracturing and brecciation.

The ore in general is a massive pyrite-sphalerite replacement of silicified or bleached tuffaceous sediments. The medium to dark gray sphalerite is commonly even-textured and tends to be fine to medium-grained. Light yellow pyrite occurs in rounded grains and cubic crystals in about equal proportion to sphalerite in the massive ore. Chalcopyrite and galena are locally present in certain portions of the shoots. A study of old assay data indicates that the silver values are closely related to higher lead content and the gold values correspond to higher copper content.

Gangue minerals include grey silicified tuffaceous sediments, bleached tuffaceous sediments, minor white granular quartz, local white to light brown carbonate, and post-mineral gouge. Much of the massive sulphide ore is free from gangue minerals except for pyrite. The north end of many shoots appear to have replaced silicified tuffaceous sediments and the south extensions replaced bleached micaceous tuffaceous sediments. Some white mica and chlorite may be of hydrothermal origin but this is questionable in a metamorphic terrane of this type.

Four ore shoots have been discovered in the mine up to the time of examination in 1952 as shown on Plate XII. Production had come from the two centrally located shoots; the other two were only developed to a minor extent. These four shoots developed in remarkably similar structural and lithologic environments and contain similar types of minerals.

The two productive shoots plunge from 30 to 40 degrees north in the plane of the main foot wall fault. These shoots had an average strike length of about 50 feet, widths ranging from 5 to 15 feet, and plunge lengths of about 200 feet. Both shoots appear to have tapered up and down plunge.

The mineralizing solutions may have a common source with the nearby quartz latite porphyry dike of Laramide (?) age. The east segment of the dike dips 70° - 80° southwest toward the downward extension of the pre-mineral fault zone. Ore solutions followed the emplacement of the dike and the intersection of the Boston fault zone and the dike may have served as the main channel which conducted the ore solutions into the country. As the solutions rose they followed the favorable north-plunging structures up to the south.

Favorable north-plunging structures formed by the intersection of the northeast-striking, west dipping tuffaceous beds and basic bands with the N. 20° - 30° striking Boston fault zone. The conditions at this intersection served as favorable loci for ore development and consequently the attitude of the resulting ore shoots coincide with the intersection zone. The specific locale of the four known shoots appears to be controlled by the intersection of competent basic bands on one side of the Boston fault with other basic bands on the opposite side. This intersection forms a rigid north-plunging inverted trough. The drag of these two competent bands against the main pre-mineral fault crushed and brecciated the less competent tuffaceous sediments in the underlying crescent-shaped wedge. Subsequent faults wrapped around these competent blocks and prepared the tuffaceous sediments further for ore solutions.

The ore solutions replaced the favorably prepared tuffaceous sediments in the crescentic-shaped trap underneath the adjoining basic bands (see 96-foot level plan, Plate XII). Locally, silica replaced the area nearest the intersection and sulphides replaced the adjoining ground to the south.

The reason for the comparatively short plunge-length of the shoots may be found in the nature and attitude of the basic bands. The basic bands on opposite sides of the main fault have been faulted together and therefore have different thicknesses, strikes, and dips. Thus along the main fault these basic bands join and separate within short distances. Where the bands separate and the tuffaceous sediments form one wall of the main fault, the ore shoot feathers out or thins down to non-commercial widths. This can be observed in the adit-level near the collar of the winze where the top of the "south stope" shoot is exposed (Plate XII). Another example is at the bottom of the "north stope" shoot below the 96-foot level. The two basic bands present on the 96-foot level separated a short distance below and the ore pinched out completely in 40 feet of depth. Development on the 162-foot level revealed the main fault, one basic band, and only disseminated pyrite, local silicification, and minor sphalerite was encountered.

U. S. Navy mine

The mine development has exposed a vein which occupies a portion of the Navy thrust fault west of Copper Basin (Plate X).

Few data were available on the history and production. It is probable that some early production is not included in the following information from Minerals Resources and Minerals Yearbook volumes:

1914	Lead sulphide from U.S.Navy.
1928-29	Four cars lead ore containing gold and silver.
1937-38	U.S.Navy opened for first time in years. Shipped 1600 tons zinc-lead ore to Yarnell mill and 244 tons lead ore to smelter.
1943	Shipped 71 tons from U.S.Navy, Black Diamond, and Silver Gulch.
1948	Shipped 162 tons zinc-lead ore from U.S. Navy and Silver Gulch.
1949-51	Shipped 175 tons zinc-lead ore from U.S.Navy.

The U.S.Bureau of Mines reportedly opened the main workings in 1943 and sampled the mine.

The mine is developed by an inclined shaft which collars at an elevation of about 5,425 feet. The collar of the shaft was caved in 1952 and the only accessible working was an adit S. 75° W., 700 feet from the shaft at an elevation of about 5,265 feet. The adit trends approximately N. 75° E. and connects with the inclined shaft, but was caved at 515 feet from the portal. One of the westernmost stopes below the adit-level was open and could be inspected. The shaft reportedly has an inclined depth of 520 feet but follows the undulating surface of the north-dipping vein and the inclination is said to range from 20° to 50°; thus the vertical depth is not known.

The Navy thrust fault and associated vein strikes N. $70^\circ - 80^\circ$ E. and dips 20° to 50° SE. in the mine vicinity. The country rock is foliated, blocky Precambrian quartz diorite. Quartz monzonite of the composite Copper Basin stock occupies the thrust fault about 500 feet west of the adit portal. Within the adit the 1 to 4 feet thick mineralized gouge and breccia is assumed to be this same quartz monzonite dike. This evidence indicates a Laramide (?) age for this deposit.

The important ore minerals, collected on the dump and in the adit, were coarse galena and light to medium brown sphalerite. Both of these sulphides occur in crystals as large as 1 inch in diameter. Cubic and pyritohedral forms of light yellow pyrite are present. Pyrite is locally abundant in some parts of the veins and nearly absent in other parts. Chalcopyrite is sparingly present in some of the ore.

Gangue minerals comprise altered quartz diorite and quartz monzonite (?), gouge, granular and crystalline quartz, and brown carbonate. Some of the galena-sphalerite ore is interbanded with quartz. Much of the massive galena ore appears to be fissure filling and the mixed galena-sphalerite ore, in part at least, replaced sheared wall rocks, quartz, and carbonates.

The 515 feet of accessible adit exposes the Boston thrust fault as a 2 to 4 foot zone of mineralized gouge and breccia. Sulphide breccia fragments indicate a post-mineral period of movement. The foot wall is silicified and locally impregnated with pyrite, carbonates, and minor amounts of galena and sphalerite. No ore has been mined on this level but an old stope begins about 5 feet down the dip of the fault below the floor and about 350 feet from the portal. The stope is partially gobbed but the shoot must have had a strike-length of about 100 feet and a dip-length of about 50 feet. Lessees have shot the back down to recover 2 to 12 inch stringers of massive galena and obscured the evidence indicating the original thickness of the shoot. The hanging wall of the thrust fault flattens from 40° to 20° in the shoot area, forming a structural terrace. There is a suggested plunge of about 20° east in the plane of the thrust. The N. 70° E. striking thrust plane controls the main shoot, but minor steep veins follow a N. 10° E. fracture system. Some of the ore from this shoot is reported to have been massive galena carrying high silver values.

The detailed control of the one ore shoot is undoubtedly the roll or flattening of the thrust hanging wall. In reference to the more general control the Boston fault zone projects throughout the main workings. The small N. 10° E. veins correspond to this direction. The Boston fault zone is mineralized by local pyrite, chalcopyrite, galena and sphalerite, from 1500 to 4000 feet south of the U.S.Navy mine.

Whether the ore solutions moved up the thrust fault from the west root portion the Copper Basin stock or whether they moved up vertically along the Boston fault zone might be important in further exploration at this mine.

Silver Gulch mine

The Silver Gulch mine openings explored a flat vein-fault striking N. 70° E. and dipping 5° - 15° SE., which is about 1000 feet north of the northeast extension of the Navy thrust fault (Plate X).

Minerals Yearbooks records small shipments in 1943 and 1948 from the Silver Gulch mine. This ore was silver-rich galena and possibly some sphalerite.

The mine has been developed by surface cuts and shallow inclines down the dip for about 50 feet. No ore was exposed at the time of the visit but massive galena specimens were observed on the dump. The country rock is massive Precambrian amphibolite.

Mint mine

The Mint mine openings explored the south contact of a small isolated quartz monzonite body southwest of Copper Basin (Plate X).

No production data could be found and no stoped ground was observed. The prospect is developed by an inclined shaft, an adit, two parallel open cuts, and shallow pits. The shaft is inclined 40° on a N. 40° E. bearing. In 1952 the water level in the shaft was at 70 feet, measured on the incline, and the total extent of the workings is unknown. Two parallel open cuts, about 25 feet apart, trend N. 40° E. for about 75 feet from near the collar of the inclined shaft. About 300 feet north from the shaft an adit was driven southeast toward the open cuts. The adit level consists of about 300 feet of workings.

The adit explores a brecciated southeast-trending contact zone between late Cretaceous (?) or early Tertiary (?) quartz monzonite and Precambrian quartz diorite. It is possible that the quartz monzonite occupied a southeast extension of the Navy thrust fault but definite evidence is lacking. The breccia zone is strongly altered to clay minerals, and minor quartz and sulphides locally cement breccia fragments. The open cuts expose a N. 40° E. brecciated fault zone that probably intersects the previously-mentioned contact zone southeast from the face of adit.

Minerals observed in the adit and on the shaft dump are pyrite, chalcopyrite, galena, sphalerite, and minor bornite. Pyrite cubes as much as 2 inches in diameter are present. Gangue minerals are brown weathered carbonate and glassy quartz. Sulphides replace carbonate, quartz and altered country rock.

Nine Strike mine

The Nine Strike mine openings have explored the east contact of the Copper Basin stock by four adits (Plate X). All the workings were inaccessible in 1952. The main adit was driven from the floor of Copper Basin east to northeast a reported total distance of 2700 feet. The dump from this adit consists chiefly of Copper Basin quartz monzonite and Precambrian granodiorite. No gossan or sulphide minerals were observed on the dump. Three other adits, located east of the main adit and from 500 to 600 feet higher in elevation, were driven east in Precambrian granodiorite or granodiorite porphyry. Minor amounts of limonite gossan and disseminated pyrite were observed on the dumps. A definite vein zone was not located on the surface near this property.

Mines North of Copper Basin

At the north end of Copper Basin a pyrite vein strikes N. 25° E. and dips 75° - 85° SE (Plate X). This vein transects quartz monzonite porphyry, Precambrian aplite and granodiorite porphyry. The vein was traced for over 2000 feet along the strike and the width of the mineralized zone ranges from 1 to 3 feet wide. The vein contains glassy quartz, altered wall rock, and local lenses of limonite gossan or pyrite. At one point on the vein a shaft, inclined 70° E., has developed an 18 inch zone rich in pyrite and containing minor amounts of galena. The shaft was filled with water to within 12 feet of the collar in 1952.

In the general area north of Copper Basin there are numerous quartz veins striking north to northeast. The general mineralogy suggests that the veins are associated with the Copper Basin stock, but a few Precambrian tourmaline-quartz veins were observed, especially in the vicinity of West Spruce Mountain. The more important ones will be mentioned briefly.

The Dean mine is north of Copper Basin and can be reached by roads from the north (Plate X). The mine development has explored a N. 55° E. striking and 55° SE. dipping vein which contains pyrite, galena, sphalerite, and chalcopyrite in a glassy quartz gangue. Observable workings consist of a caved shaft and adit. Small shipments have probably been made from this mine.

The Mistake mine is located at the north boundary of the mapped area and appears to occupy the projected northward extension of the Finch Fault (Plate X). The vein material is associated with a strong shear zone as much as 20 feet wide which strikes N. 45° E. and dips 40° - 50° SE. The observed vein material consists of glassy quartz and white carbonate replaced by minor quantities of pyrite and galena. The country rocks are amphibolite and granodiorite porphyry. Small shipments reportedly assayed high in silver and gold. The mine has been developed by a shaft and several adits; all were inaccessible when visited.

Schumate mine

The mine is located in a deep canyon which borders the north side of the rhyolite volcanic neck (Plate X).

No production data were found for this property.

Three partially caved adits were driven from the bottom of the canyon; two trend southwest and one bears northeast. The adits were all driven in Precambrian metasediments. Local quartz lenses, as much as 8 inches thick, and some disseminated pyrite were observed in the workings. Light yellow pyrite cubes in a matrix of brown weathered carbonate were found on the dump at the northeast adit.

Mines southeast of Copper Basin

A vein striking N. 20° W. and dipping 70° NE. is located on the east side of Copper Basin near the south boundary of the mapped area (Plate X). Four patented claims cover the exposed part of the vein. No road has ever been built to the property and access is by a trail southwest from the end of the road which traverses the high ridge bordering the east side of Copper Basin. The property has been developed by a shaft and four adits. The workings were inaccessible except for one adit which extends southeast under the vein outcrop. Small piles of pyrite, galena and sphalerite in a glassy quartz and pink carbonate gangue had been sorted from surface workings on a 3-foot shear zone which contained narrow streaks and pockets of ore. The accessible adit explored the ground underneath these showings but failed to penetrate any sulphide of value.

Another prospect is located about 500 feet west of the road that extends south along the high ridge east of Copper Basin and about one mile south of the junction of this road with the Copper Basin road (Plate X). Two patented claims cover the exposed portion of the vein. The vein strikes N. 70° W., and dips 60° NE. Three shallow caved shafts have explored a shear zone in Precambrian granodiorite. Minor amounts of cellular limonite and disseminated pyrite were observed on one dump.

<u>Prospects in South Copper Basin</u>

Four breccia pipes are exposed near Copper Basin Wash east of the diorite unit of the Copper Basin stock (Plate X). One shaft of unknown depth and two short adits have explored two of these pipes. Glassy quartz cements angular non-rotated breccia fragments of quartz monzonite. Minor amounts of pyrite were observed in one adit on the west side of Copper Basin Wash and strong limonite gossan and some oxidized copper minerals were found on the surface of the largest pipe east of the wash.

About a half mile south of the above pipes there is a group of four more pipes which are strongly altered but show little sign of sulphide mineralization (Plate X).

A brecciated zone about 600 feet east of Copper Basin Wash at the south boundary of the mapped area contains disseminated pyrite and minor galena.

Late Tertiary (?) and Quaternary Deposits

Mercury prospects

Mercury mineralization is associated with late Tertiary (?) rhyolite dikes and breccia zones in the southwest part of the area. No roads are present in the area and access can best be gained by walking south from the McNary mine or west from the road between the McNary and Mint mines (Plate X).

Lausen and Gardner (1927, pp. 35-44) described the deposits during an active period of exploration. There was no activity in the area in 1952.

Rhyolite and rhyolite breccia dikes are numerous enough in this area to be classed as a "swarm." The predominant trends range from north to N. 70° W. The dikes occupy faults in Precambrian quartz diorite and granodiorite. Diabase, other basic dikes, and tourmaline quartz veins are present and the rhyolite locally intruded along one side of these older units.

Chalcedonic quartz and white calcite, reminiscent of hot spring deposition, are present in some rhyolite breccia zones and to a lesser extent in faults in rhyolite and Precambrian rocks. Limonite, hematite, and pyrite are locally concentrated in the chacedonic quartz deposits. Cinnabar was observed in a few places at the edge of pyrite crystals. Cinnabar is probably present in some of the limonite and hematite but is difficult to distinguish. The oxides and sulphides appear to occur in minor cracks and fractures and no continuous vein zone was observed.

An impression of values can be gained from the following assay data given by Lausen and Gardiner (1927, pp. 42-43).

> "Two samples, designated Nos. 1 and 2, were taken in the shaft of this claim and were assayed. No. 1 was across 4 feet 7 inches of the vein on the north side of the shaft and contained .04 percent mercury. No. 2 was across 3 feet on the south side and contained .06 percent mercury. Samples taken across 1 or 2-inch stringers would probably show 2 or 3 percent of the metal. A few pieces, the size of a man's head, that contained more than 5 percent quicksilver, have been taken out."

The exact location of the claim mentioned above is unknown.

Placers in the drainage from this area have contained small particles of cinnabar and natural amalgam in the concentrates (Wilson, 1937, p. 42).

Placer deposits

Small-scale placer operations have been carried on in the lower reaches of Copper Basin Wash and associated tributaries. Some placer gold has been recovered from streams in the southwest part of the area that drains into Skull Valley. Many of these placers are outside of the mapped area.

Willson (1937, p. 41-44) described the Copper Basin placer deposits in some detail and little can be added from the present study.

Small scale placering has probably been done in the district since its discovery, but the only active recorded period was from 1929 to 1937. There was no placer activity in 1952.

The source of the gold, especially the coarser nuggets, was undoubtedly the Precambrian tourmaline quartz veins. In general the Laramide (?) deposits have low values in gold but may have made important contributions to the finer portions of the placers.

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