THE OCCURRENCE OF GOLD AT THE GETCHELL MINE, NEVADA.[1]

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ABSTRACT.

The Getchell veins are lenticular replacement bodies lying along arcuate branches of a complex range-front fault system. The fault zone cuts all rocks of the district and is tentatively dated as late Tertiary.

The more intensely mineralized portions of the deposit form a shallow blanket with roots that project downward into areas of sparse mineralization. The gold shoots are restricted to areas of intense mineralization.

Native gold and native silver are the only economic minerals. The great bulk of the gold occurs in minute but microscopically visible particles. Some gold may also occur in submicroscopic particles and some may be in solid solution in pyrite and carbon.

The ore minerals, dissolved in alkali sulfide solutions, are believed to have been deposited when the sulfide ion concentration in the hydrothermal liquid decreased, making unstable the double sulfides of gold, iron, and arsenic.

The Getchell deposit is similar in many ways to the Nevada quicksilver deposits and present-day hot-spring deposits. The Getchell ore occurrence may represent a gradation from the common epithermal gold deposit to the cinnabar deposit. It is therefore placed close to the feeblest end of the epithermal group.

INTRODUCTION.

In the past, a number of important gold mines have produced millions of dollars in gold from ore in which no gold could be seen. The Getchell gold deposit is the most recently discovered of these mines of "invisible" gold. Because gold had not been seen in the ore, either at Getchell or at similar deposits, the problem of the state, or occurrence, of the gold has been subject to considerable controversy. A prime purpose of the present study has been to ascertain whether the modern microscopic and polished-section techniques are capable of shedding some light on the problems of gold occurrence.

Location and History.—The Getchell mine is located in the northeastern corner of the Osgood Range in east-central Humboldt County, Nevada (Fig. 1). It lies 26 miles north of the town of Golconda and some 15 miles northwest of Red House, the nearest railroad station.

The gold deposit is in the old Potosi mining district but was itself not discovered until 1934. Between 1934 and 1945, the deposit was extensively explored by both surface and underground workings. A 1,000-ton mill was erected, and in 1944 and 1945, the Getchell mine had become the largest gold producer in Nevada. In 1945, mining had nearly exhausted the oxidized ore and it became apparent that milling practices in use were not suitable for

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[1] Undertaken in part as a Samuel Franklin Emmons Memorial Fellowship award.

treating the sulfide ore. Mining operations were halted and an intensive metallurgical research program was begun. In 1947, a pilot mill was started treating 100 tons a day. By the summer of 1948 a satisfactory flow sheet had been developed and construction began on a 1,500-ton mill. Production, at present limited to 1,000 tons a day, will be increased upon the completion of the mill.

Acknowledgments.—The writer is indebted to the staff of the Getchell mine, and particularly to Mr. R. A. Hardy, for financial assistance and whole-hearted cooperation. G. S. Koch and R. S. Creely ably assisted in the two summers of field work.
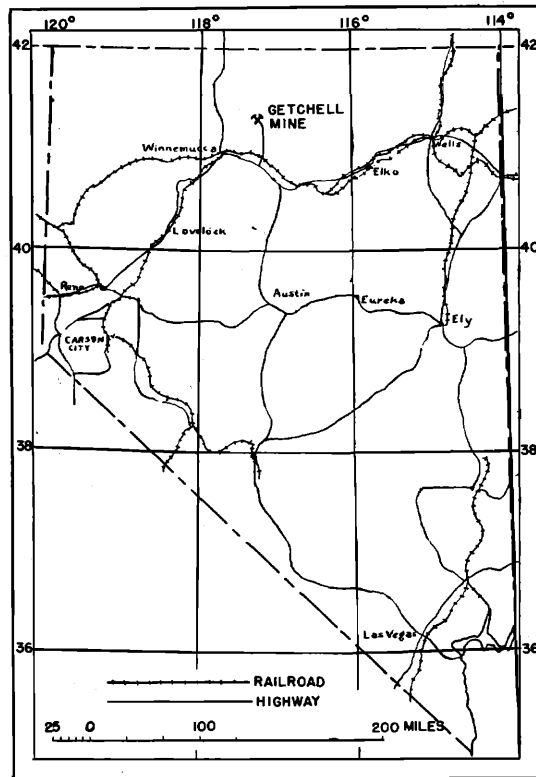

FIG. 1. Index map of Nevada showing location of Getchell mine.

The laboratory portion of this study has been carried on with the aid of a Samuel Franklin Emmons Memorial Fellowship.

The faculty of the Department of Geology at Harvard University has made valuable criticism and given much assistance in the laboratory work. Professor L. C. Graton in particular has donated generously of his time and experience. All polished sections were prepared by Mr. Charles Fletcher at the Harvard Laboratory of Mining Geology.

GENERAL GEOLOGY.

The Osgood Range is apparently a typical Great Basin Range. Its steep flanks are topped by rolling uplands in the center of the range and it is bounded on at least one side by normal faults that are responsible for the uplift of the range.

The mountains are composed of sediments of Paleozoic age that have been cut by a series of faults into isolated structural blocks (16).[2] The attitude of the rocks varies widely from block to block. The sediments are intruded by a large stock of Mesozoic granodiorite and a series of related dacite porphyry dikes, and by small Tertiary andesite porphyry dikes. Basalt flows and a small body of rhyolite tuff are products of Tertiary volcanism. Irregular patches of the tuff near the mine have been silicified and closely resemble the opalite found in certain Nevada quicksilver deposits (3).

FIG. 2. Getchell Mine, Nevada. The scars on the hill behind the camp mark the footwalls of the open pits.

Descriptive Geology of the Getchell Mine.—The bedded rocks of the mine area are interbedded limestone and carbonaceous argillite (Fig. 5). The most striking feature of the sediments is the extreme lenticularity of the limestone beds, as shown in Figure 3. Limestone formations several hundred feet thick may drastically thin or pinch out completely in a strike length of less than 1,000 feet.

The sediments are intruded by the large granodiorite stock, the northeastern lobe of which is cut off by the fault zone along which the gold ore bodies occur. Later andesite porphyry dikes, trending more or less northerly, are apparently localized in and near this fault zone. A roughly conical pipe of altered rhyolite porphyry tuff lies to the east of this fault.

[2] Numbers in parentheses refer to Bibliography at end of paper.

Structure.—The principal structure of the sediments is a fold whose axis plunges at about 45° northeast. Along the southern limb of the fold, the sediments strike northerly and dip moderately to the east, and to the north they are isoclinally folded and dip to the northeast. This structure has been important in localizing the Getchell ore bodies.

The Getchell fault zone is the dominant structural feature of the mine area. It trends in a northerly direction and is composed of a persistent, footwall strand dipping moderately to the east, with steeper, arcuate hanging-wall branches (Figs. 3, 4). The footwall strand is shown by well-developed mullion and drag-fold structures to be a rift fault, along which the hanging-wall block moved an unknown distance with respect to the footwall block (Fig. 6). Later normal movement, indicated by steeply pitching slickensides engraved on the mullion faces, took place along this footwall strand. The steeper, hanging-wall branches were formed at that time and occur above flexures in the footwall fault where the dip flattens, as shown in Figure 4.

ORE DEPOSITS.

General Features.—The gold ore bodies are sheet-like masses that lie along the various strands of the Getchell fault zone. They extend at least 7,000 feet horizontally and 800 feet down the dip, and vary in width from a few feet to more than 200, averaging about 40 feet wide. The vein pattern, extremely complex at the surface, becomes simpler with depth and, deeper than 800 feet below the surface, all the branch veins apparently join to form a single persistent structure, illustrated in Figure 4.

Gangue Minerals.—The veins consist of sheared and mineralized argillite and limestone cut by quartz and calcite veins and containing a soft, plastic gumbo that has replaced the sediments. The gumbo is the principal gold-bearer. Barite, gypsum, fluorite, and chabazite are minor gangue minerals and occur in small isolated pockets within the veins. The shape of the more heavily mineralized portions of the veins is that of an irregular, relatively shallow blanket with three root-like projections that extend downward into the region of sparse mineralization, as illustrated in the longitudinal projection, Figure 3. The three "roots" of the ore body appear to mark the original major channelways along which the hydrothermal fluid passed in greatest abundance.

There are striking differences in the mineralization within as contrasted with outside these major channelways. Within these roots, now marked by high-grade gold ore, deposition has been largely by non-selective replacement. In these areas, all rock types and early gangue minerals have been replaced with equal ease by the gangue minerals and the sulfides of the later phases of the ore-forming period. The larger part of the material deposited here is apparently magmatically derived, and the process of deposition has been one of wholesale replacement. In the sparsely mineralized stretches between the ore shoots, replacement has been limited and extremely selective, and all material except small amounts of auriferous pyrite appears to have been locally derived. In these outlying areas of the veins, mineralization involved the local reworking of rock minerals with only minor introduction of material
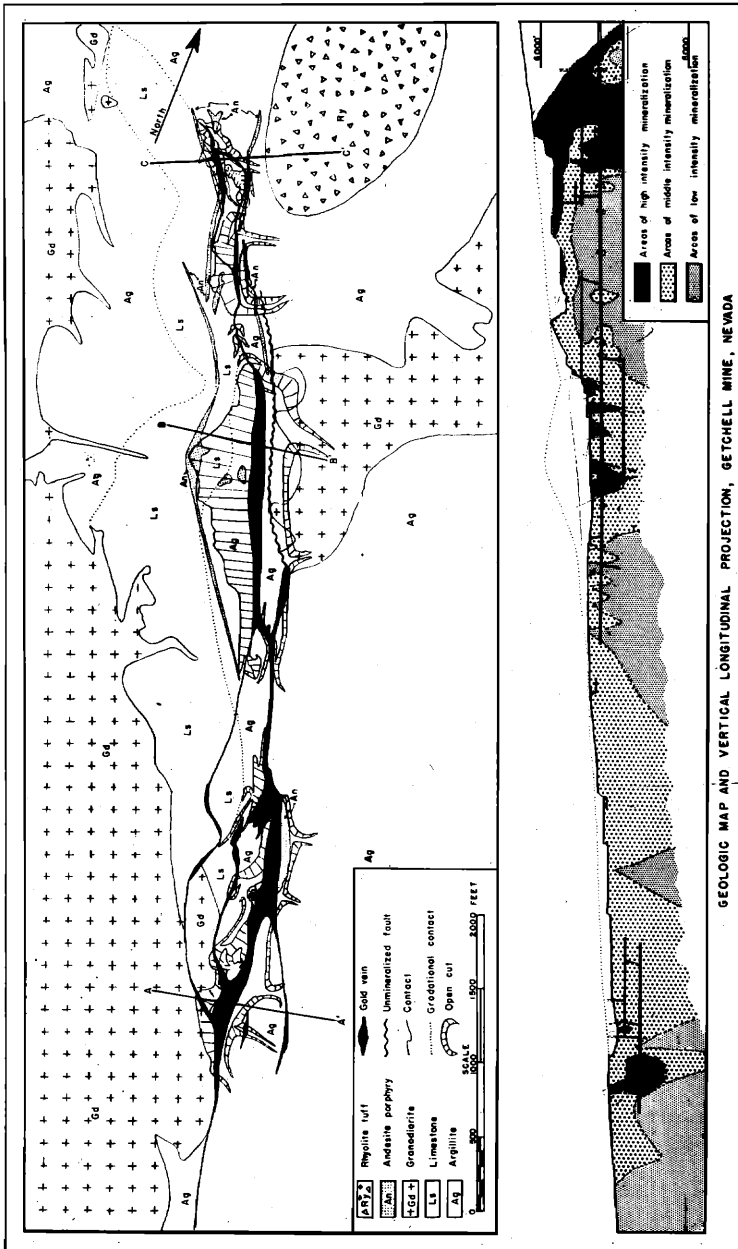
FIG. 3.   Geologic map and vertical longitudinal projection, Getchell mine, Nevada.

SECTION A-A'

SECTION B-B'

SECTION C C'

	Rhyolite tuff		Limestone		Unmineralized fault
	Andesite porphyry		Argillite		Contact
	Granodiorite		Gold vein		Gradational contact

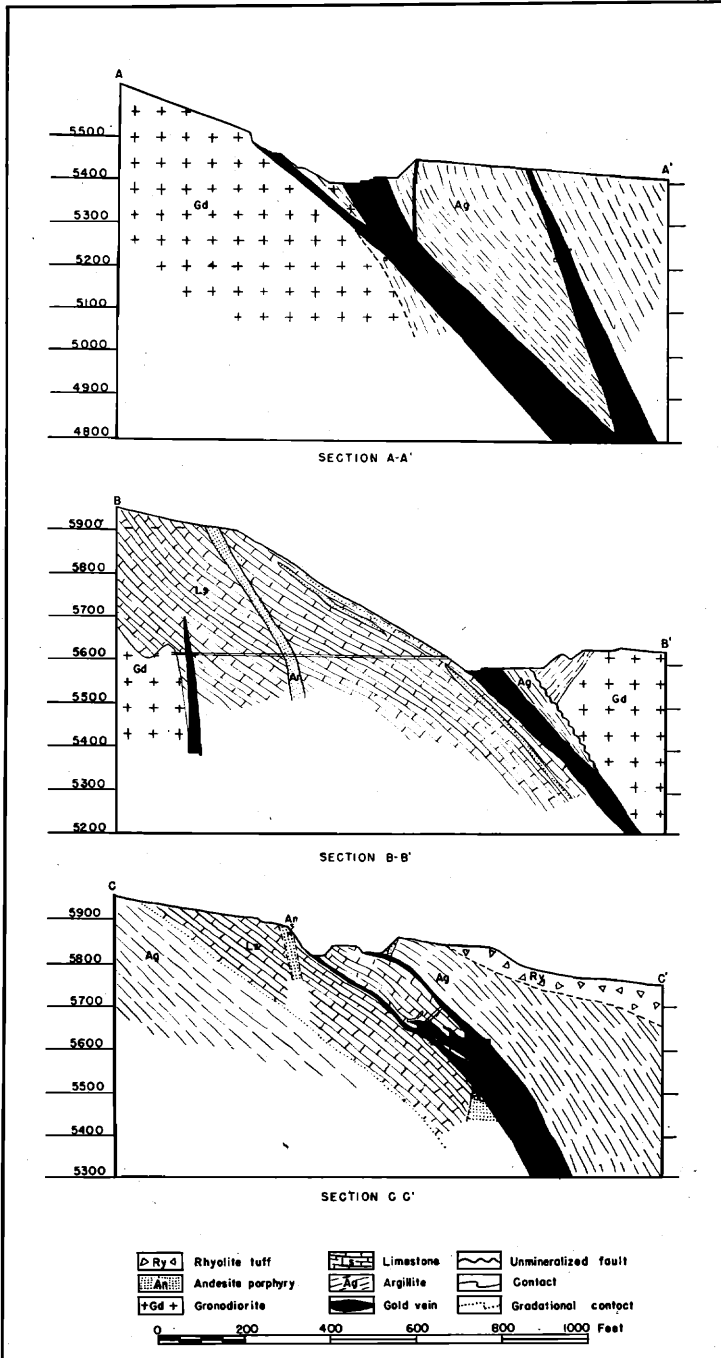0   200   400   600   800   1000 Feet

FIG. 4.   Geologic cross-section through Getchell ore body.

foreign to the rocks. Thus, calcite veins are restricted to beds of limestone and quartz veins and lenses occur only in argillite.

The gumbo, the important gold-bearer, is unusual in that while it appears to be a fault gouge, it actually consists of minute subhedral quartz crystals embedded in a nearly submicroscopic intergrowth of quartz and amorphous carbon (Figs. 9, 11, 12, 14). In places veins of gumbo several feet wide and parallel to the surrounding sedimentary rocks end abruptly against unsheared limestone or argillite. That it is of hydrothermal origin is indicated by the fact that in thin section it appears actually to replace the wall rock, as shown in Figures 8, 9, and 10. It was apparently formed in two stages. First was the replacement of wall rock by fine-grained quartz to form a porous aggregate of subhedral quartz crystals in narrow bedding veins. In the second stage, carbon, probably derived from underlying argillite, was introduced into the porous quartz veins and was deposited interstitially to the quartz. Rather surprisingly, those portions of the veins that contained the most gumbo and would ordinarily be considered to be but slightly permeable, remained the most permeable sections of the veins and the later hydrothermal solutions were there concentrated.

Metalliferous Minerals.—The deposition of important amounts of gangue minerals had apparently stopped by the time of maximum deposition of sulfides. Pyrite and minor pyrrhotite are the earliest sulfides and in the ore shoots they occur in irregular porous masses, as shown in Figure 26. In the outlying segments of the veins pyrite has a tendency to assume euhedral forms. Replacement has been the important mechanism of deposition of all later sulfides within the ore shoots (Fig. 12) whereas fracture-filling is predominant in the sparsely mineralized zones (Fig. 13).

Arsenopyrite is present in minute euhedral crystals and is almost entirely restricted to the portions of the veins occurring in the andesite porphyry.

Marcasite constitutes about 5 percent of the iron sulfides in the central channelways but is rare or non-existent in the outlying areas. It occurs as minute laths and as irregular shells or rims encircling earlier pyrite grains.

Arsenic sulfides are the most abundant of the metalliferous minerals and, unlike pyrite, are entirely restricted to the areas within the veins that now contain noteworthy quantities of gold. Orpiment is apparently earlier than realgar and is found only in isolated pockets, characteristically occurring in low-grade sections of the veins. In these pockets, orpiment constitutes as much as 40 percent of the mineralized material and is veined and coated by realgar. Realgar occurs throughout the commercial ore bodies in amounts ranging from 1 to 10 percent. It shows such a consistent relation to gold that the presence of realgar is usually a strong indication of good values.

Stibnite, like orpiment, occurs in restricted pockets in which it is present in two unusual forms. Stibnite occurring in narrow, pipe-like bodies is present in a series of clusters of hair-like crystals so minute as to suggest a soft black velvet coating on the rocks. The molybdenum mineral ilsemannite is closely associated with this stibnite. In one small area the fractures in the rock are coated with metastibnite, a red paint or stain which has been shown by X-ray photographs to be finely dispersed stibnite. Similar forms of

stibnite have been found in the sinter and the hot spring muds at Steamboat, Nevada (4).

Cinnabar is present as a thin coating on calcite and chabazite crystals in a narrow and discontinuous branch vein. While it does not occur in com-
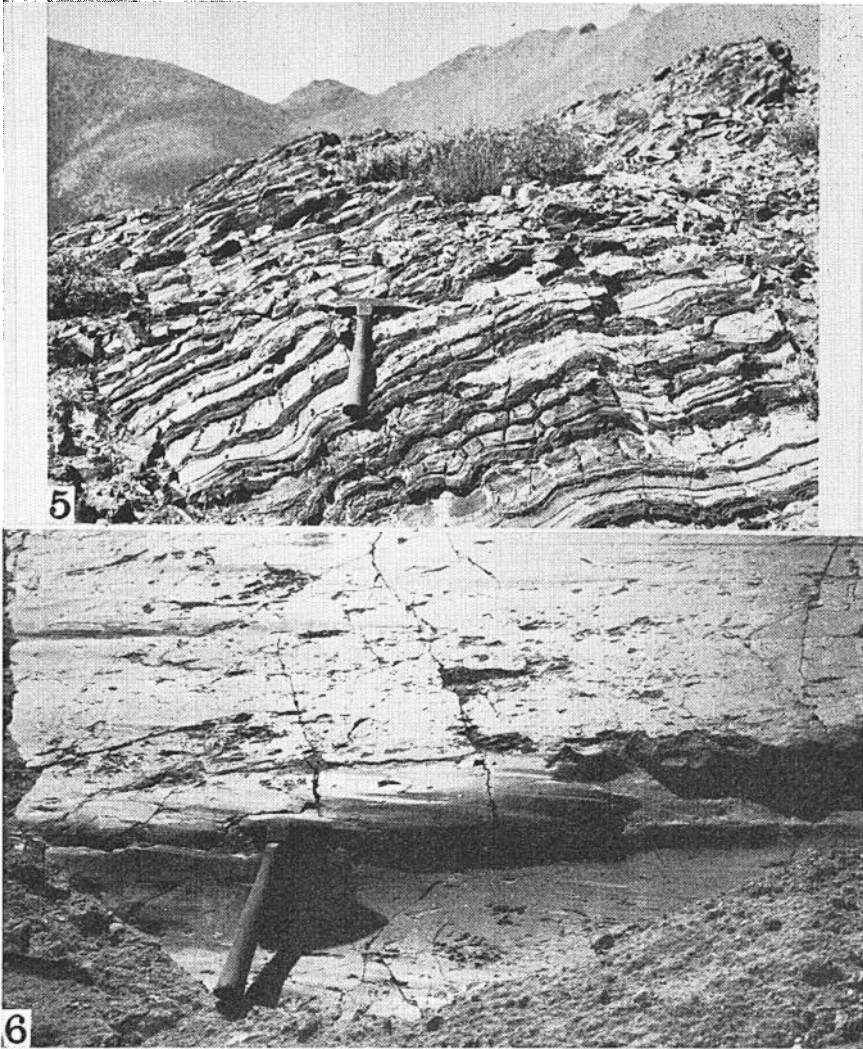

FIG. 5. Interbedded limestone and argillite from Getchell mine area. The vein material has replaced portions of this formation, preserving the thinly laminated structure.

FIG. 6. Fault surface that forms the foot-wall strand of the Getchell vein system. The nearly horizontal mullion structure is strong evidence in favor of horizontal fault displacement along this surface.
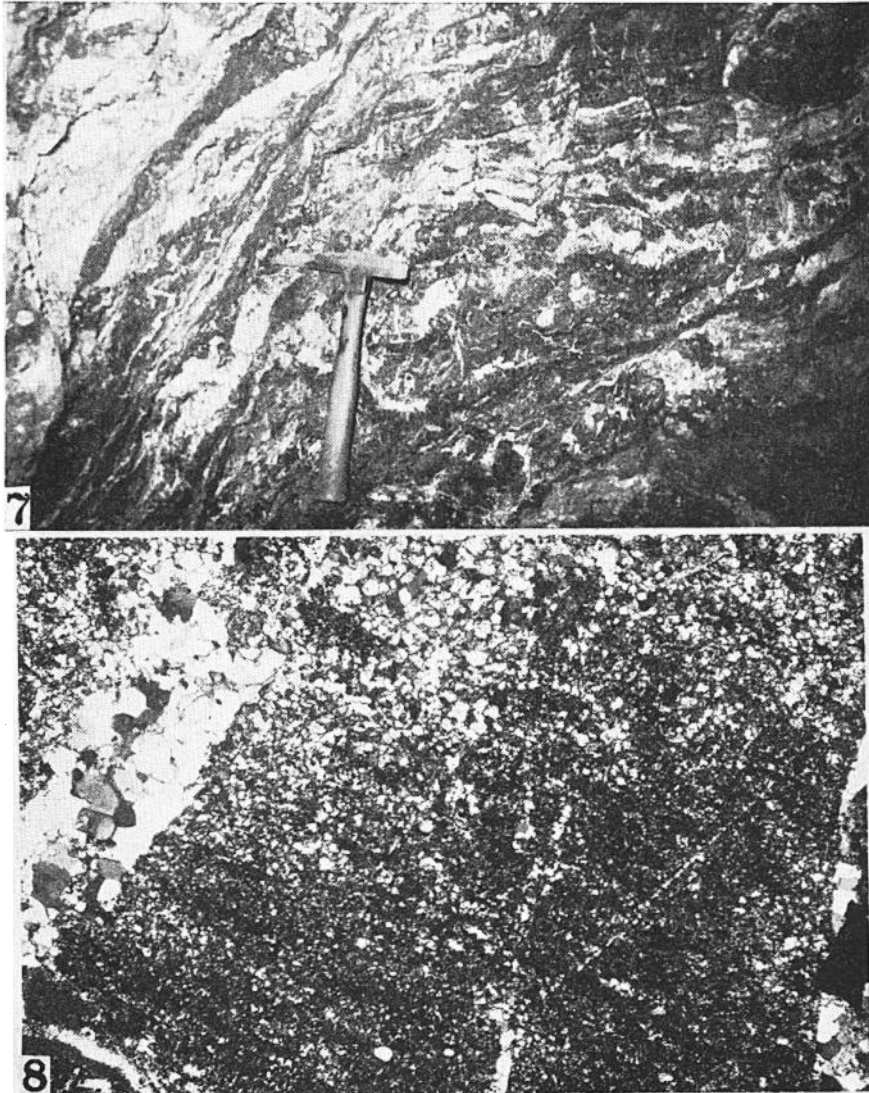
FIG. 7 Typical vein material. Realgar veins, appearing as white bands, preserve the sedimentary structure. The black bands are of carbonaceous gumbo and unreplaced linestone and argillite. A minor pre-mineral normal fault cuts and warps the bedding.

FIG. 8. Photomicrograph of thin section of vein material, showing incipient silicification of argillite. The fine-grained argillite shown in the lower half of the picture has been replaced by coarse quartz grains. In the process of this replacement the carbon has been largely removed. The texture of the replacing quartz grains is similar to that of the quartz in the rich ore gumbo. Cross nicols, × 50.

mercial quantities, its very presence suggests a possible genetic relation between Getchell and the cinnabar deposits of Nevada.

Magnetite is apparently the latest of the metalliferous minerals associated with gold, and is the one most closely related to gold. It occurs only in microscopic particles and has been seen only in the gumbo and andesite. It is plainly not a detrital mineral. It is so closely associated with gold that any polished sections containing a cluster of magnetite grains have also some gold close at hand, generally within a millimeter (Figs. 22, 23).

PRECIOUS METALS.

Distribution.

Economic amounts of gold are entirely restricted to the veins, within which the richer ore shoots are loci of more intense mineralization. The richer gold ore is in the shape of a relatively shallow, discontinuous blanket with three root-like downward projections, as illustrated in the projection in Figure 3. The cause of localization of the ore shoots is discussed in a later section. The portions of the veins between the rich shoots, and the wall rock for several hundred feet on either side of the veins contain everywhere a small amount of gold, ranging from 0.01 to 0.08 ounces per ton. The commercial gold ore has been developed over a strike length of 7,200 feet and to a depth of as much as 800 feet. At this depth, rich gold ore is still present.

Visible Gold.

Because of the crumbly, non-cohesive nature of the gumbo, it was necessary in polishing specimens of the ore for microscopic investigation to develop a technique which would allow the polishing of even the smallest particles of gold. Mr. Charles Fletcher of the Laboratory of Mining Geology at Harvard University prepared the polished sections and his patience and skill have aided immeasurably in this investigation.

In the early stages of the microscopic study, extremely few gold particles were to be seen, and it became apparent that the polishing methods in use were not satisfactory for this problem. The polishing treatment finally adopted represents the results of progressive trials and improvements. In this process, the sample to be polished is first impregnated with a liquid bakelite resinoid and then baked. It is next sawed and is again impregnated. Following this it is placed in a bakelite briquette, and is ground to a smooth surface. After a final impregnation, it is ready for the several stages of polishing on the Graton-Vanderwilt polishing machine. The multiple impregnation is necessary because a single impregnation penetrates only a short distance into the section. By using this method of polishing and by using a microscope with a Zeiss 2-millimeter objective lens, N.A. 140, mineral grains having an area of as little as 0.1 square microns are visible and recognizable.

The properties of gold are so diagnostic as to make it an ideal subject for such a detailed study. Its brilliant yellow color makes it easily recognized in larger particles but when the grain size decreases to a diameter of less than
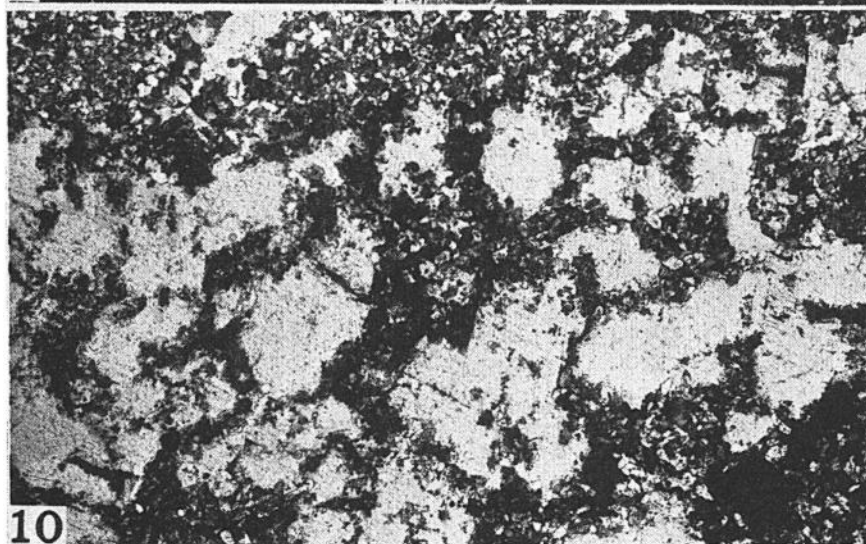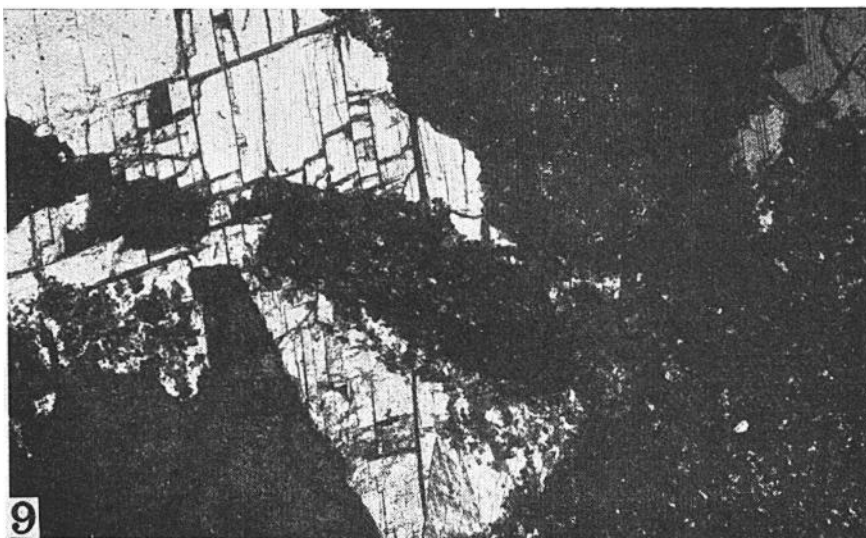
FIG. 9. Photomicrograph of this section of vein material in limestone. The white, coarse-grained calcite is replaced by the carbon-rich ore gumbo that appears black, and by realgar, the shattered mineral in the lower left. Cross nicols, × 50.

FIG. 10. Photomicrograph of thin section of coarse calcite partially replaced by high-grade ore gumbo. The calcite in the irregularly mottled grains shows the same extinction over the entire section and represents isolated remnants of a once much coarser grain. Quartz occurs in the small clear grains and the black material is carbon. The texture of the replacing gumbo is typical of the richer material. Cross nicols, × 48.

one micron, the color becomes less noticeable and other features must be used for identification of minute particles. The extreme softness of gold prevents the achievement of a perfect polish on small grains, but every minute grain of gold has a characteristic undulant, "egg-shell" texture (Figs. 24, 25, 26). Gold is exceeded in reflectivity only by native silver, platinum, and copper, and the egg-shell texture may be used for positive identification of all particles to a limit of microscopic visibility at a magnification of $\times$ 2,500.

The described polishing technique is probably not perfect; indeed it is reasonably certain that some grains that would have been above the limit of visibility, had they remained in place and been polished, were torn from the polished surface. The proportion of grains thus lost undoubtedly would increase as the grains became smaller. Furthermore, some grains of visible size may not have been seen. Even with the most careful polishing, the extreme softness of gold makes inevitable its depression below the impregnated surroundings. Hence there is an oblique band around every gold grain that gives no reflection up the tube of the microscope. The *width* of this band is a function of the relative softness of gold to its surroundings and thus tends to be independent of grain size; but the *relative importance* of this relief shadow increases with decreasing size of gold grain. If the diameter limit of visibility of a grain of gold ideally polished is "x," and the width of the oblique shadow in actual polishing is "y," then an imperfectly polished grain must have a diameter of $x + 2y$ to be visible. All grains smaller than this would appear only as tiny black pits.

Finally it is certain that not all grains possessing a true diameter above the ideal limit of visibility that were actually present at the plane of polish were seen. This plane must have touched many grains, large and small, so far from their equator of maximum diameter that the intercept at the plane of polish did not attain practical visibility.

In this investigation, more than 2,600 gold particles were identified and measured. The results of these measurements are given in Figure 17. The graph shows the enormous increase in the abundance of gold particles with decreasing grain size. It also shows that the great bulk of the gold is in the rare and widely scattered larger particles having an exposed area of more than 1,000 square microns.

All gold particles seen in the Getchell ore are roughly lenticular in cross-section. To get a better idea of the three dimensional shape of the particles, the length and width of individual grains visible on the polished section were measured and, after further polishing away a measured thickness from the section, the dimensions of the same grains were remeasured; this procedure was repeated, step by step, at about 2-micron depth intervals, until one after another of the grains disappeared. It is apparent that the gold particles are lenticular in three as well as two dimensions. Knowing the approximate dimensions of individual grains and the number of grains visible on every polished surface, it is possible to estimate the minimum gold content of the polished specimen and to compare it with the assay value of the specimen from which the section was prepared.

The average polished section may be regarded as a rectangular block with dimensions $2 \times 1 \times 1$ centimeters. Each block weighs about 2.7 grams and 336,000 such blocks would be required to make a ton of ore. Gold with some silver present has a specific gravity of about 17.3. One cubic centimeter of gold weighs 0.556 Troy ounces, and ore containing 0.5 ounces of gold per ton must contain 0.9 cubic centimeters of gold. If the gold occurred in cubes one centimeter on an edge, an enormous number of polished sections might have to be prepared before this gold would be encountered. If the assumption is made, however, that gold is present in grains having an average dimension of $1 \times 1 \times \frac{1}{2}$ microns and is so distributed through the ore that each mass the size of a polished section holds a representative amount, then one ton of ore containing 0.5 ounces of gold would contain 2×10^{12} grains of gold. Every polished section block would contain an average of 5.94×10^6 gold particles. Because of the abundance of non-opaque minerals in the Getchell ore, it is possible to see not only minerals actually cut by the polished surface but also minerals lying as much as one micron beneath the surface. Thus each polished section may be visualized as being divided into a series of flat sheets one micron thick. Every sheet would contain 1,045 particles of gold. There are many assumptions in these calculations, but the results give at least a rough idea of the number of gold particles one might expect to see if all gold occurred in visible grains of the size specified. Increasing size of grains greatly reduces the number.

The investigation of particle size and number has shown that there is little correlation between the assay value of the sample and the calculated value of the polished section. As an example, five polished sections were prepared from an ore sample which was shown by assay to contain 1.06 ounces of gold per ton. In one of these sections, fewer than 20 gold particles of micron size or larger were seen, while another contained more than 800 particles of the same or larger size. The other three varied widely but fell within these limits. The conclusion must be reached that the gold is not regularly distributed, even in a small sample, but rather that it is strongly concentrated in certain bands and lenses about one centimeter wide. The five sections mentioned above were all prepared from gumbo, so this spotty gold distribution is apparent even within the gumbo which is generally an excellent indicator of rich ore.

Most of the visible gold is intimately associated with the fine-grained quartz-carbon matrix of the gumbo. Many of the particles partially rim larger quartz grains. Some of the gold is rather uniformly distributed throughout the gumbo in small isolated particles. This is slightly more abundant in those bands in the ore that contain more carbonaceous material. These particles average 4 square microns in exposed area, somewhat larger than the average of all visible grains. In addition to the uniformly but sparsely distributed particles, gold grains also occur in clusters of roughly lenticular outline (Figs. 27, 28). These gold-rich pods are composed of abundant gold grains that average one half of a square micron in exposed area. They are commonly so abundant that under low power magnification the entire area of the lens has a pale yellow color. Yet within the lenses gold occupies less than 1 percent of the area. Like the individual grains mentioned above, this gold occurs in

the carbonaceous matrix, and quartz grains within the gold pods stand out as barren islands. The lenses are as much as 100 microns wide and are commonly several millimeters long. These aggregates of gold particles have been seen only within the gumbo and are commonly elongate parallel to the structure of the gumbo. Even within the gumbo, these lenses are rare and the presence of one or two in a sample will give an erratic high assay.

Gold in these pods is intimately associated with magnetite and carbonaceous matter. Magnetite is slightly more abundant than gold and, like gold, is very loosely embedded in the matrix and is easily removed by rubbing. During the impregnation of the polished sections, both magnetite and gold from some of these lenses were pulled out from the carbonaceous matrix by the inrush of resinoid after evacuation and were carried along open cracks in the section, finally forming inclusions in veinlets of resinoid. This magnetite seldom . shows a euhedral form and generally occurs in irregularly rounded masses and angular fragments. It is largely restricted to the gumbo. Rarely, both gold and magnetite are rimmed by a mamillary halo of carbon (Fig. 23). There is thus a strong suggestion that there has been a redistribution of small amounts of carbon during or after the main period of gold and magnetite deposition. Magnetite occurs not only in the rich gold lenses but also disseminated through the gumbo in small isolated grains. No magnetite has been seen outside of the ore bodies.

In addition to the occurrences discussed above, gold is found rarely as inclusions in the sulfides. All of the major sulfides contain some visible gold, but pyrite and marcasite are the principal hosts. Less than 1 percent of the total number of gold particles seen occurs in sulfides. It may be that the larger gold particles were deposited almost entirely in the gangue, but there is some evidence to suggest that such is not the case. The gold particles occurring in the sulfides are far more loosely held than that in the gangue. The particles in the sulfides that were not wrested from the surface during grinding and polishing are invariably removed when the immersion oil is wiped from the section. So it is probable that the sulfides contain far more gold of visible size than can be seen in polished sections.

All forms of pyrite and marcasite contain some visible gold, but the more porous varieties are more commonly hosts for the metal (Figs. 25, 26). Where gold particles occur as inclusions in subhedral crystals of pyrite they are generally in the outer parts of the crystals. None has been seen in the cores of these crystals.

Summary of Occurrence of Visible Gold.—Visible gold occurs sparsely disseminated through every rock type in the veins and is particularly abundant in the gumbo. Gold distribution is quite similar to that of marcasite and realgar, and is more restricted than pyrite. The only minerals that are strikingly associated with gold are carbon and magnetite. Laboratory tests show a strong direct relation between carbon and gold, and the gold content of carbon concentrates increases as the purity of the concentrate is increased.

The size of the particles of visible gold ranges from a fraction of a micron to nearly one millimeter; the smaller grains are far more abundant than the

larger. The weight-distribution curve shown by the broken line in Figure 17 shows that the larger part of the mass of gold is from the less abundant, larger particles.

The more porous forms of the sulfides contain more gold than the solid euhedral crystals. There is apparently a strong, direct correlation between the amount of surface exposed in the host minerals, that is, the porosity, and the amount of contained invisible gold.

"Invisible" Gold.

It is probable that not all the gold occurs in visible grains. The "invisible" gold may occur in any of three forms. First, it may occur in the native state in particles below the limit of microscopic visibility. Second, it may be present in a compound such as the telluride, likewise submicroscopic or else undetected. Finally, it may occur in solid solution with the sulfides or adsorbed onto the surfaces of carbon and the sulfides. This may be visualized as a two- or three-dimensional solution, depending on whether gold was adsorbed onto the host structure after or during the growth of the latter. An adsorbed film of gold on a pre-formed mineral differs from gold in atomic dispersion through the host mineral structure only in that it is a planar rather than a three-dimensional feature.

The frequency distribution chart in Figure 28 has been prepared on a logarithmic scale. This chart shows the great range in size between the gold atom and the smallest visible particle.

Gold in Solid Solution in Sulfides.—According to present theory, two major types of solid solution occur in nature. First is substitutional solid solution. In this, ions of the minor (guest or solute) component occupy the position in the crystal lattice that would be normal for ions of the dominant (host or solvent) component. Depending on whether the radius of the guest is larger or smaller than that of the host, there will be an expansion or contraction of the resulting crystal structure. As the difference between the radii of the host and foreign ions decreases, the degree of possible solid solution increases. The growth of such a solid solution is caused by adsorption of foreign ions onto the growing surface of the host. At the surface of a crystal at any stage of its growth there is an unsaturated field of force, since the outermost ions at this stage have not enough neighbors to satisfy their normal coordination. During growth, ions in solution make coordination by attachment to the thin surface of the crystal. A foreign ion in the solution may respond to this field of force and be added to the growing crystal, playing the role of proxy for a dominant ion in the crystal, provided that the radii of the corresponding ions or atoms in question do not vary by more than about 15 percent of the size of the smaller. The covalent radius of the iron ions in pyrite is 1.23 A° and the octahedral covalent radius of gold is 1.40 A° (25, p. 170). So the covalent radius of the gold ion is within 15 percent of that of iron, and gold should be able to enter into substitutional solid solution in pyrite.

The second type of solid solution is known as interstitial solid solution. In this, the solute atoms are believed to be dispersed in the structure of the

solvent atoms or ions. The solute or foreign atoms are introduced in addition to, rather than in place of, the host or solvent ions. This type of solid solution is rare and generally occurs where the foreign ion is distinctly smaller than the host.

Synthetic Auriferous Pyrite.—Maslenitsky (22) added gold chloride and colloidal gold in the course of synthesis of pyrite. He was able to control the amount of gold contained in the pyrite up to a maximum amount of about 9.7
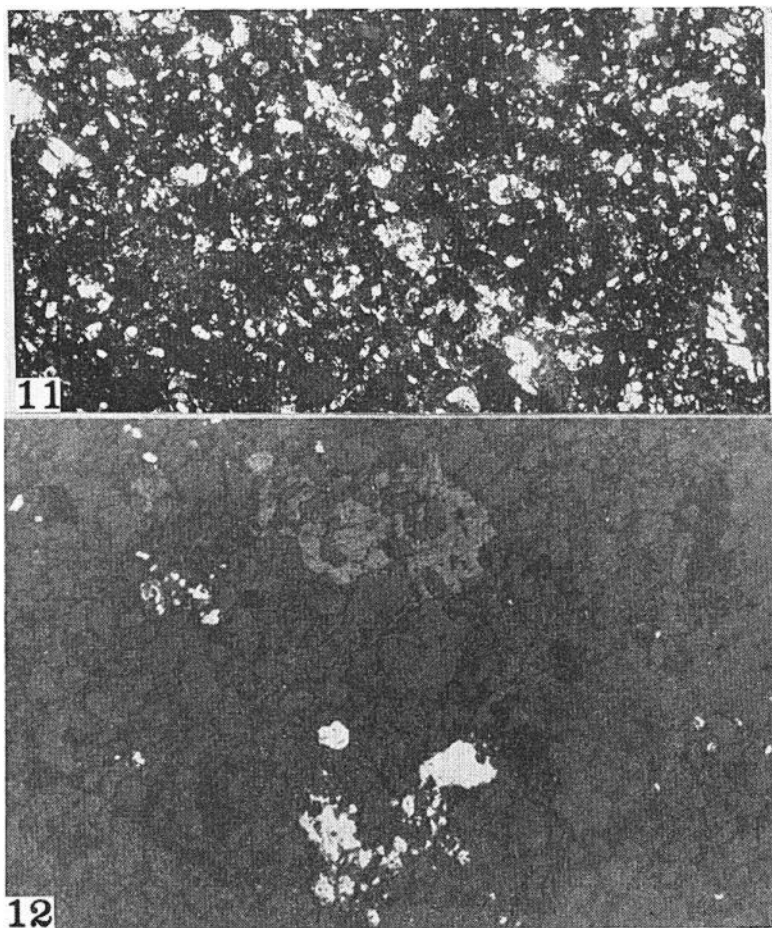

FIG. 11. Photomicrograph of high-grade gumbo. The nearly uniform size of the quartz grains is characteristic of the richer material. All quartz grains are embedded in carbon. Although the host rock has been entirely replaced, the sedimentary structure has been preserved. Cross nicols, × 40.

FIG. 12. Photomicrograph of polished section of ore gumbo. Pyrite (white) and realgar (light gray) have replaced the fine-grained quartz-carbon intergrowth interstitial to the larger quartz grains, leaving the latter as residual islands. This gangue texture is typical of all high-grade portions of the ore. × 45.
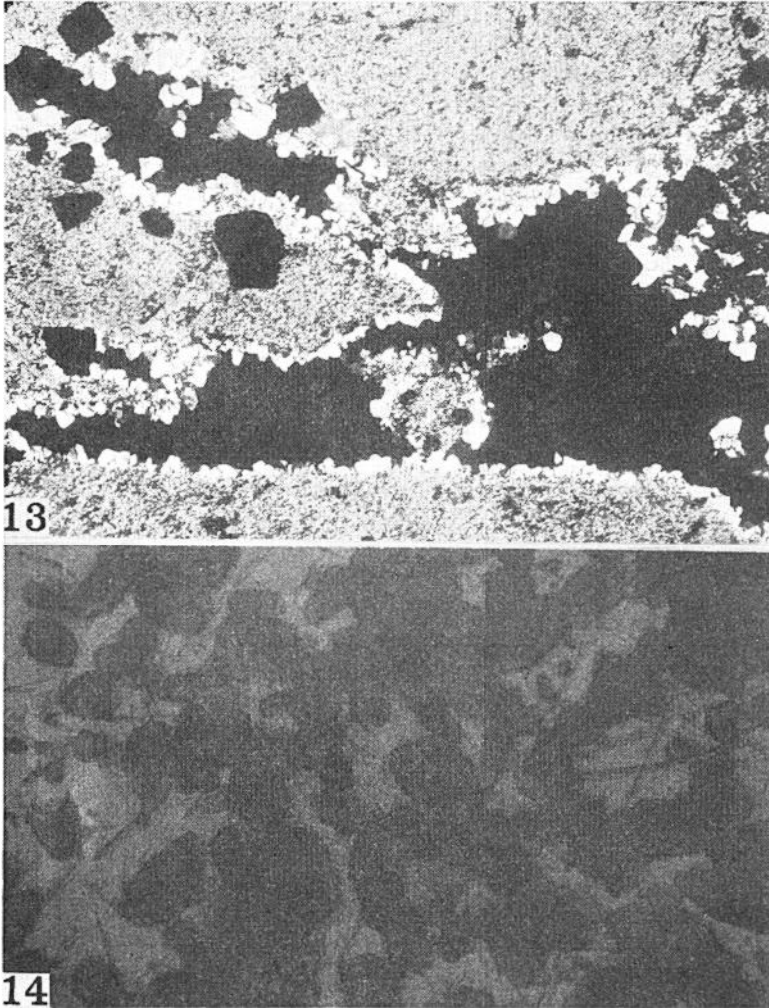
FIG. 13.   Thin section of realgar and vein stuff.   The realgar appears black in the forked vein that is rimmed by thin layers of quartz crystals.   The black euhedral crystals outside the vein are of pyrite.   The vein cuts a fine-grained quartz-sericite intergrowth that is an unreplaced fragment of argillite.   Such material is not a conspicuous gold-carrier.   Cross nicols, × 40.

FIG. 14.   Photomicrograph of polished section of realgar in ore gumbo.   The realgar (light gray) surrounds islands of subhedral quartz crystals, having replaced the fine-grained quartz-carbon matrix of these grains.   × 310.

ounces per ton.   Investigation of the auriferous pyrite under × 1,200 magnification revealed no gold and the gold may have been in solid solution in the pyrite.   The method of polishing used in the preparation of these polished sections is not known.   In many cases specimens that reveal no gold when

polished on a cloth lap may be shown to contain abundant visible gold after repolishing on a lead lap.

Kuranti (18) prepared a synthetic auriferous pyrite in which gold was invisible even under the highest magnification possible. Again the method of polishing may have obscured some visible gold. The gold was shown by spectrographic analysis to be distributed uniformly throughout the pyrite, and X-ray pictures of the pyrite showed that the pyrite lattice constant varied with increasing gold content, reaching a constant value at 2,000 grams of gold per ton of pyrite. The evidence may indicate that solid solution of gold in pyrite is possible. Unfortunately the original Japanese publication describing this work is not available.

Natural Auriferous Pyrite.—It is probable that gold in solid solution in pyrite may be synthesized. A naturally occuring example of such solid solution has not been previously described, although many writers have attacked the problem.

R. E. Head (15) suggested that at least some gold in particles of micronic diameter in pyrite occurs in tiny leaves or flakes coated with a magnetic iron mineral, lying between crystallographic planes in the pyrite. Such a feature might suggest exsolution of gold. Edwards (6, p. 130) states that such fine gold particles rarely show the ordered arrangement in the pyrite that would be expected if this were so.

Haycock (14) prepared a frequency-distribution chart of sizes of gold particles in 50 Canadian ores, and found that the greatest number of grains were well within the range of microscopic visibility. Over 75 percent of all the visible gold falls within the microscopic rather than the megascopic range. By projecting this curve into the range of submicroscopic sizes, Haycock concludes that gold of colloidal sizes has only slight importance and gold in solid solution in sulfides may be of even less economic value. He points out that until the natural existence of gold in solid solution in pyrite or other sulfides is proved to be significant, it is more in accord with probability to stress the importance of normal gold particles of submicroscopic size.

Auger (2) studied pyrite from various gold deposits in Canada. He made spectrographic analyses of the pyrite and found that the spectral gold lines were inconsistent, even within one deposit. He concluded that gold, whenever present, is unevenly distributed in the pyrite crystals and appears in the spectrum only when the analyzed sample contains small particles of gold. Auger felt that this evidence strongly suggests that gold does not take part in the structure of the pyrite crystal as solid solution, and that gold is not precipitated at the same time as the pyrite. His study included only natural pyrite and his conclusions do not constitute a denial of the possibility of gold in solid solution in pyrite. It might be well to mention that gold is relatively insensitive to spectrographic analysis, as the lower limit of sensitivity is about 0.001 percent.

Pyrite and arsenopyrite from the Dolphin East Lode, Fiji (28), were found to contain as much as 33 ounces of gold per ton, although only a few particles could be seen microscopically. The sulfides were heated to 600°

C and, on cooling, were again examined microscopically. Abundant gold particles, enlarged to visible size by the heating, were formed by the coalescence of submicroscopic gold. Stillwell interprets these results as an indication of the presence of gold in limited solid solution in the sulfides. Heating of the gold-bearing pyrite, however, would tend to preserve, rather than terminate, any state of solid solution. It is perhaps more probable that this Fiji gold is present in independent particles larger than the gold unit cell. The coalescence of smaller particles represents a change to a form having a lower, and thus more stable, surface energy, if the original gold is in colloidal-sized particles.

Back-reflection X-ray photographs of pyrite from Amador, California, taken at Harvard, show that the structure of some of the pyrite is distorted, having a cube edge of 5.477 kx, while other of the pyrite has the normal undistorted structure with A_0 equalling 5.405 kx. Spectrographic analyses indicate that the distorted material contains about 5 ounces of gold per ton, approximately ten times as much as is contained in the normal material. While both types of pyrite appear to be the same in polished section, nitric acid brings out a differential etch pattern, the auriferous pyrite being etched more deeply than the lower grade material. This evidence strongly suggests that at least some of the Amador gold is in solid solution with the pyrite.

Similar etching or tarnishing was noted at the Simmer and Jack Mine on the Rand some years ago (12). At that deposit, and at adjacent mines, it was found that one of the dependable signs of better-than-average gold values in the Reef was the rapidity of tarnish of the pyrite at those places. The pyrite of rich stretches of the conglomerate would develop strong irridescence on a freshly blasted face within a day or two. This differential tarnish may have been brought about by the presence of gold in solid solution in some of the pyrite.

Auriferous Pyrite in Getchell Ore.—Pyrite from the ore shoots in the Getchell mine contains some small particles of visible gold, commonly located near the edges of the pyrite grains or near open spaces within the grains. Further gold has apparently been lost during polishing. It is probable, however, that the gold of visible sizes is not abundant enough to account for the total gold value of the pyrite. No visible gold has been seen in polished sections of pyritic concentrates from the ore, although they contain about 0.5 ounces of gold per ton.

Samples of the sulfide concentrates were heated to 600° C in the presence of sulfur vapor in a sealed tube. Each polished section prepared from this material reveals from 10 to 20 particles of gold averaging 0.3 microns in diameter. All particles occur at the boundaries of pyrite grains (Fig. 24). Heating of the pyrite apparently brought about two related processes. First, it caused the submicroscopic gold to migrate toward the margin of the host grains, thus ridding the bulk of the pyrite of its gold. Second, the heating caused the coalescence of the gold present to form, in some instances, visible grains. This heating process cannot be assumed to make all the grains visible; probably only the richer pyrite grains contained enough gold to yield visible particles. This experiment suggests that the pyrite may not contain uniform
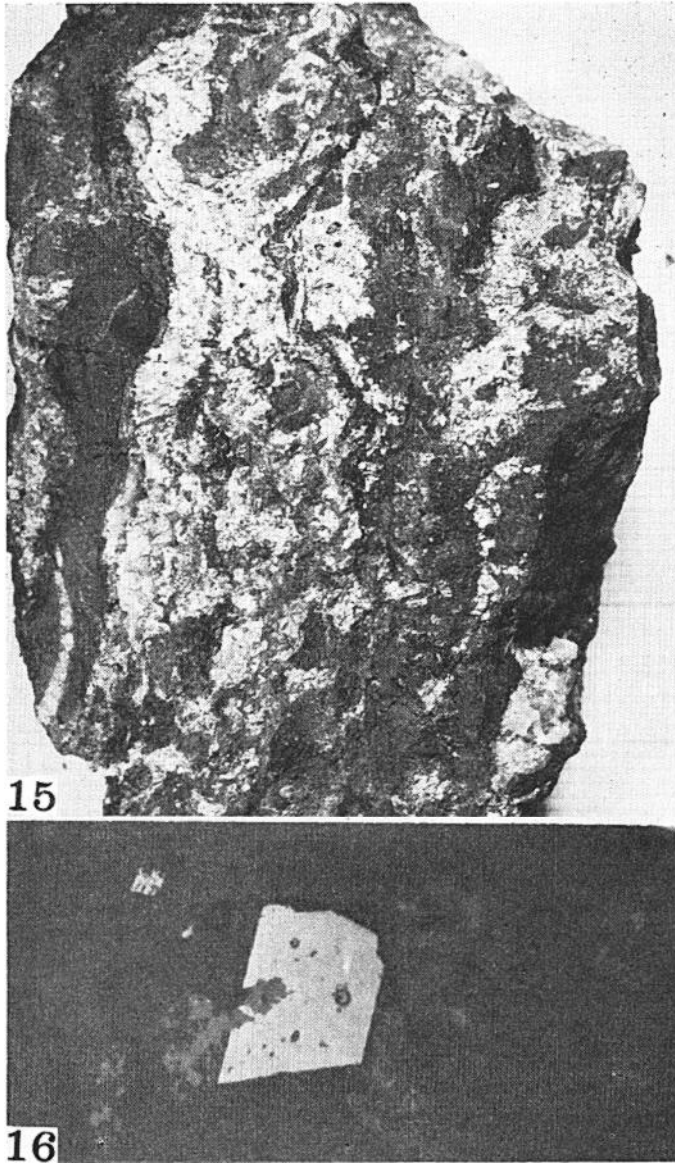
FIG. 15. Hand specimen of typical gold ore. The light material is realgar, occurring as bedding veins in limestone. Irregular patches of gumbo have also replaced the limestone. About half natural size.

FIG. 16. Photomicrograph of polished section of ore in andesite porphyry. The white euhedral crystal is arsenopyrite and the irregular light gray mass is magnetite. Magnetite apparently has replaced both the gangue minerals and arsenopyrite. × 425.

amounts of gold, although, as previously stated, all pyrite contains some gold. Grain size of the pyrite is apparently not an important factor in determining the amount of contained gold; large grains show no more tendency to contain visible gold than do the smaller particles. This experiment proves the existence of submicroscopic gold in the pyrite, but it does not prove or even suggest whether the gold occurs in atomic or ionic division or in particles with dimensions exceeding those of the gold unit cell.

A comparison between auriferous pyrite and artificially prepared activated charcoal containing gold may seem extreme, but a brief description of the charcoal and its effects on gold may shed some light on the problem of auriferous pyrite. Metallurgists have long been aware of the fact that charcoal is able to adsorb gold selectively from a complex solution. This property is utilized at the Getchell mine where activated charcoal is used to remove gold from cyanide solutions. The charcoal probably adsorbs gold in the form of a double cyanide with sodium or calcium.

Gross and Scott (13), largely on the basis of chemical tests, found evidence suggesting that the gold adsorbed on the activated charcoal was not in the metallic state. However, polished sections of treated charcoal containing nearly 200 ounces of gold per ton were prepared at the Harvard Laboratory of Mining Geology, and in these, abundant metallic gold was found present in small but visible particles (Fig. 27). It is possible that the adsorbed gold cyanide salt, being extremely unstable, may have broken down to metallic gold after standing for some months. Such a breakdown, however, would probably form extremely minute particles and it is apparent that the gold seen in the polished sections of the charcoal is too coarse-grained to have been formed in this way. So some other factor may have brought about the coalescence to visible size. Whatever this force may be, it is strong enough to overcome the adsorptive attraction of the charcoal for the gold, as the adsorbed ions appear to have been pulled from the carbon surface to form larger particles. It is also possible that the first gold adsorbed on the charcoal acted later as nuclei for the growth of metallic gold particles. The first layer or film of gold atoms is assumed to have been deposited by adsorption, while further growth may have been accomplished by normal forces of crystallization.

Like the visible gold in the sulfides, these gold particles are extremely loosely held on the surface of the charcoal and but few can escape removal during polishing. The gold particles in the charcoal and pyrite alike occur either along the margins of the host grains or bordering minute open spaces within the grains. In the case of the charcoal, the amount of gold that can be adsorbed varies with the exposed surface of the charcoal, and most gold occurs in the more porous material.

It may be merely coincidence that the pyrite and marcasite in the richest ore are porous and have irregular surfaces, whereas the pyrite that occurs away from the ore shoots is generally more solid and more regular in outline. But the fact that visible gold associated with sulfides generally occurs in the irregular, porous forms of the sulfides suggests that this porosity may have been important in localizing the gold. Laboratory tests have shown that a sub-

stantial part of the gold occurring with the sulfides is associated with the fine-grained portions of the latter. A large grain has less exposed surface than an equivalent volume of small grains, and hence can adsorb less material. An euhedral crystal likewise has less surface area and therefore less adsorptive capacity than an irregular shape of the same volume.

The mechanism of adsorption is here proposed to explain the precipitation of gold on pyrite, other sulfides, and, to a larger extent, on the carbon in the ore. This process differs from that of solid solution in that the latter involves adsorption of the foreign ions *during* the growth of the host. If the bulk of the gold associated with pyrite represents a solid solution of gold in the sulfide, then gold would have been introduced into the ore at the same time as the sulfides, and the amount of gold should be roughly proportional to the amount of sulfides. Most of the gold values, however, are restricted to narrow bands whereas the sulfides are widespread throughout the ore bodies. Thus, it is apparent that the solutions from which the bulk of the gold was deposited travelled along more restricted channelways than did the solutions that deposited the sulfides.

It is not meant to deny the possible existence of gold in a three-dimensional solid solution in the sulfides, but rather to emphasize that any such solid solution can be of only minor importance at Getchell. Indeed, it may well be that a very small amount of gold is in solid solution with the pyrite.

Growth Mechanism of Gold Particles.—If a hydrothermal solution is unsaturated with gold, neither native gold nor any gold minerals may be formed. As was previously mentioned, however, the gold, unable to form its own mineral, may proxy for iron ions in a growing pyrite crystal. Such a proxy would bring about a solid solution of gold in the host crystal. Under these conditions, if the ratio of gold to iron in solution does not exceed the limit of solubility at a given place, all the gold may occur in solid solution in the pyrite. If the ratio is higher, the pyrite will still contain gold in solid solution and will also contain larger gold particles as random inclusions. Where the ratio is much higher, these inclusions will attain visible size.

In any deposit, the physico-chemical conditions, which may be called intensity conditions, may be expected to vary from place to place within the locus of deposition. Thus, a high-intensity zone might be fringed with areas of lower intensity. In the former area, gold would be deposited from hot, concentrated solutions to form discrete particles as well as to occur in solid solution in pyrite. In the outlying, low intensity zones, where deposition was from dilute solutions, the only gold deposited would be that in solid solution in the sulfides.

In the Getchell deposit, the entire zone containing the ore bodies may be visualized as an enormous block of submarginal gold-bearing rock with smaller, superimposed bodies of richer ore, as shown in the projection in Figure 3. The economically worthless sections of the veins and the wall rock contain a rather uniform amount of gold, varying from 0.01 to 0.08 ounces per ton. These low values persist as far into the hanging- and foot-wall country as does the pyrite. Pyrite concentrates from the mine, regardless of the section of the veins from which the pyrite was taken, contain a minimum of about 0.5 ounces
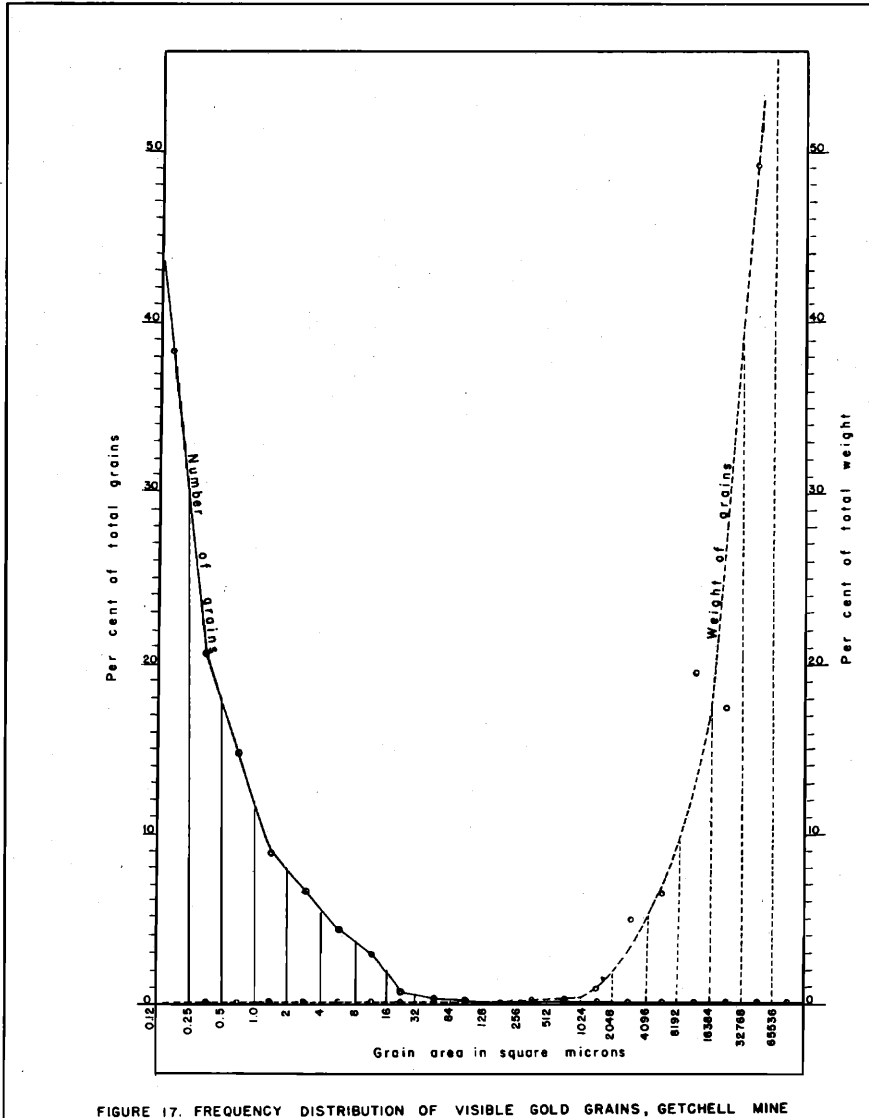
FIGURE 17. FREQUENCY DISTRIBUTION OF VISIBLE GOLD GRAINS, GETCHELL MINE

FIG. 17. Frequency distribution of visible gold grains, Getchell mine, based on measurements of 2,639 grains.

of gold per ton. The ratio of concentration of pyrite in the concentrates is about 1:50. Similarly, the ratio of concentration of gold from 0.01 to 0.5 ounces per ton is about 1:50. So the low-grade gold varies directly and closely with the pyrite.

It is to be presumed that the peripheral, submarginal gold and pyrite which

have the same extensive distribution in the wall rock and low-grade portions of the veins are more or less contemporaneous, products of deposition from the low-intensity phase of mineralization. During the growth of the pyrite, and probably also of the marcasite, it is possible that gold was being adsorbed onto the sulfide structure in extremely small amounts. This action may have taken place outside as well as within the ore body.

The extent of solid solution of gold in pyrite must be limited and is probably dependent on the temperature of formation. In a low-intensity deposit such as Getchell, the minimum solubility of gold is probably of the order of 0.5 ounces of gold per ton of pyrite. In parts of the ore body where the temperature of formation of pyrite was somewhat higher than in the areas fringing the ore bodies, the solubility might be higher.

In the outer, low-grade zones at Getchell, the gold-pyrite ratio in the solutions was probably low, and much of the gold appears to have been deposited in solid solution in pyrite. In the central channelways where more intense physico-chemical conditions existed, the ratio and limit of solubility were higher and some gold occurs in visible particles.

Van Aubel (29) has concluded that the particle size of native gold is commonly a function of the mode of formation of the associated ore minerals; when gold is contemporaneous with the enclosing minerals it is extremely fine-grained; when it is of later formation it tends to occur in coarser grains. In the Getchell ores, the peripheral gold is in general submicroscopic because only dilute, gold-bearing solutions, exhausted of much of their solute in the course of the long distance travelled from the main channels, were available and the growth of individual gold particles was limited. In the ore shoots where gold deposition from more concentrated solutions continued until the end of the period of mineralization, the gold particles continued to grow, and many achieved microscopically visible size.

The foregoing discussion is admittedly theoretical. It deals largely with that gold, or a part of that gold, which is submicroscopic and is intimately associated with the sulfides. Such gold constitutes only a small proportion of the total that occurs in the richer ore shoots. The writer feels that the evidence favoring the theory of gold in limited solid solution is strong enough to justify considering it.

Conclusions Regarding Gold Occurrence.

Gold at Getchell occurs in particles ranging in size from slightly larger than the gold unit cell to nearly one millimeter in diameter, and probably also in atomic dispersion. Submicroscopic gold is apparently more widespread than the visible metal, occurring throughout the ore body. Microscopically visible gold has a very restricted occurrence and is found only in the richer ore shoots, in which places it accounts for the great bulk of the total gold. The mass of low-grade rock far outweighs that of the ore shoots, and the actual number of submicroscopic particles is probably far greater than that of visible grains.

Discussion has been presented which suggests that the widely distributed but low-grade gold may be mainly in solid solution in the pyrite, whereas the

gold in the ore shoots is surely in discrete particles of the native metal much larger than the gold unit cell. In the very rich portions of the veins, part of the gold is in still larger particles.

The information gathered by measuring visible gold grains and presented in Figure 17 may shed some light on the question of the character of submicroscopic gold. These data have been used in the compilation of the chart in Figure 28. In order to show the full range in sizes, a logarithmic scale has been used on both the ordinate and abcissa. Since the number of grains or particles measured make up a representative sample of all the visible gold particles retained during the polishing, the curve gives an approximation of sizes throughout the ore body.

The curve in the visible range may probably be projected at least some distance into the microscopic field with some degree of reliability. The critical question is whether the curve will drop to zero at or before reaching the area of the gold unit cell following the same general pattern as Haycock's curve (14), or will continue upward along the projection from the known portion of the curve, as indicated in Figure 28.

The submarginal gold values are widely scattered through the ore body, and the mass of submarginal mineralized rock far outweighs that of ore. One ton of rock containing 0.01 ounces of gold contains 2.76×10^{20} gold atoms, and if present in truly atomic dispersion, this enormous figure would represent the number of points at which gold occurs in one ton of low-grade rock. If the gold in the richer ore were contained wholly in spheres of one micron radius, one ton of ore carrying 0.55 ounces of gold would contain 2.38×10^{11} particles. Since the rock containing submarginal gold values is so much more abundant than is the ore, it is probable that the gold in atomic or ionic dispersion is more common than are particles of greater than unit cell dimensions. If, as has been suggested, adsorption has been an active factor in gold deposition, then pyrite and carbon surfaces will contain an adsorbed film of gold ions. In the abundant, lower-grade portions of the ore body where the growth of gold was limited, large particles would not be formed, but much of the gold in the adsorbed films may have acted as nuclei for limited further gold deposition. The number of particles slightly larger than the unit cell would be enormous. In the smaller ore shoots, much of the gold grew to visible size. Granting this, the gold of atomic size is most abundant, the submicroscopic particles are the next most common, and microscopically visible grains are least abundant but represent an overwhelming proportion of the total mass of gold within the ore bodies.

Therefore the curve in Figure 28 might be expected to rise along a more or less straight line through the submicroscopic field toward the unit cell area. If the curve as indicated on the chart is roughly correct, then the frequency distribution of gold particles should be in harmony with the proposed process of gold deposition.

In the marginal phase of mineralization, gold atoms were adsorbed into the pyrite structure during the growth of the latter mineral, and the solutions contained too little gold to allow the growth of metallic gold particles. In

the major channelways the earlier minerals were being displaced upward and outward by the minerals of the more intense phase. In these channelways the solutions were hotter and the gold content was such as to allow the growth of native gold. Here the gold was adsorbed onto the surfaces of the carbon, pyrite, and marcasite to form nuclei for the growth of larger particles. Because the gold concentration in solution was higher in the central channelways than in the outlying areas of the vein and wall rock, the gold formed in this more intense phase would have more opportunity for continued growth. Hence the great bulk of economic amounts of gold is concentrated in these channelways. The ratio of visible to submicroscopic gold is far greater in these channelways than in the low-grade portions of the ore body, and the bulk of the weight of gold is in coarse particles.

The particle size of gold is therefore a function of the length of time of growth and the concentration of gold in solution. The solutions in the outer portions of the ore body contained only very small amounts of gold and there was no opportunity for growth of large particles in those places. The presence of gold particles of colloidal size does not necessarily imply deposition from a colloidal suspension. The chart in Figure 28 intimates that the colloidal-sized particles represent only the dimension attained at a given stage in the normal growth of particles. Every larger particle, being crystalline, must have grown from particles initially of the unit cell dimension.

Cause of Localization of Gold.

Structural Features.—The localization of the three deep "roots" of the rich ore, as shown in vertical projection in Figure 3, suggests that these roots lie along the respective axes of original channelways through which a greater amount of gold-bearing hydrothermal fluid passed. Solutions rising along these channels spread out into a far wider area on reaching the zone of intense shattering near the surface. The three central channelways, one in the north end, one near the center, and one near the south end of the ore bodies, remained as the major channelways throughout the period of gold deposition. Since a larger volume of gold-bearing solutions passed through these channels than through corresponding volumes of rock in the outlying region of shattering, more gold per ton was deposited within the channelways. The gold in the extensive, low-grade portions of the ore bodies is more or less contemporaneous with that in the rich ore shoots, although deposition in the shooots may have continued longer than in the more distant vein material. These richer shoots coincide with the zones of extensive development of gumbo, suggesting that even before gold deposition began, these areas were most permeable to the mineralizing solutions. The gumbo, being unconsolidated, was more permeable, and thus more favorable to transport of the gold-bearing solutions than was the enclosing rock. The concentration of carbon in the gumbo made it a better precipitant than the argillite or limestone.

In the Getchell ore, a small proportion of the total mass of gold occurs in the widespread pyrite, probably because it was deposited as a constituent part of that host. The bulk of the gold, however, is irregularly distributed in every
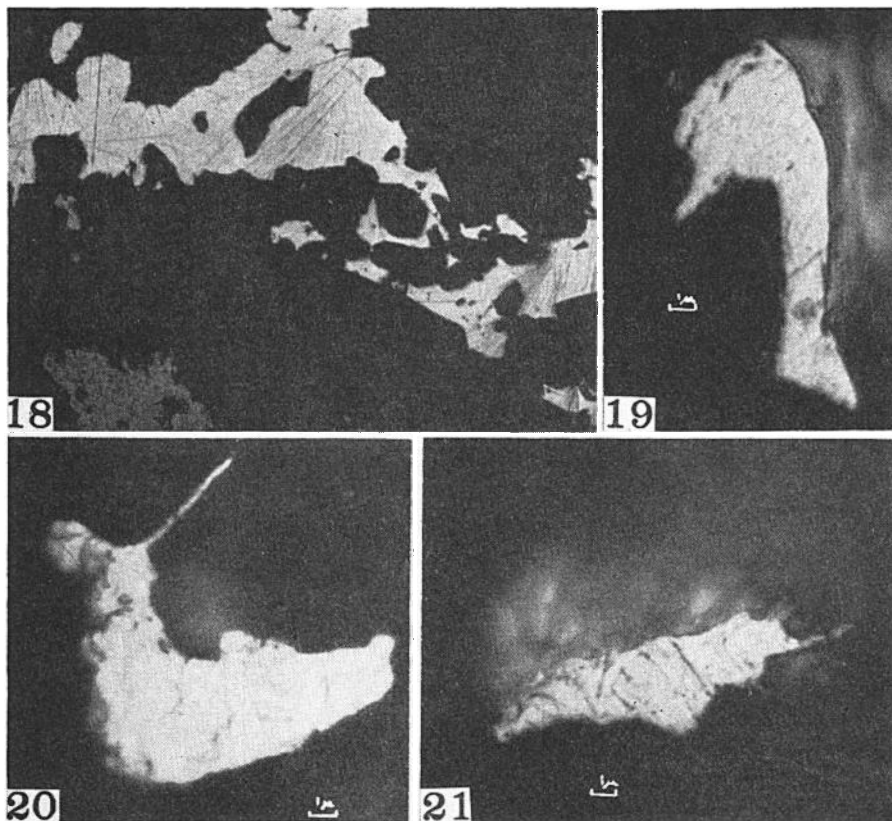
Fig. 18.   Photomicrograph of polished section of heavy media concentrate.   The large white grains are of native gold and the mottled light gray mineral is realgar. These are the largest gold grains ever seen in Getchell ore, and the only grains found that are megascopically visible.   × 70.

Fig. 19.   Photomicrograph of polished section of ore gumbo.   The large white grain is native gold; a part of this grain is submerged beneath the quartz gangue and appears as an indistinctly lighted area.   The irregular mottled surface of the gold grain shows the "egg-shell" texture so characteristic of minute gold grains. × 3,225.

Fig. 20.   Photomicrograph of polished section of gold ore, showing a relatively large gold grain that has replaced the fine-grained quartz-carbon matrix to the gumbo, molding itself around the larger subhedral quartz grains.   × 3,225.

Fig. 21.   Photomicrograph of polished section of gold ore, showing isolated gold grain.   The egg-shell texture is apparent.   × 3,225.

mineral in the ore body and therefore cannot have been selectively precipitated by any of them.   The gold was deposited in or on these various minerals apparently because they had some features in common.

Favorability of Hosts.—Since nearly every mineral in the ore has acted as a host or platform for the gold, the cause of localization of gold is probably a factor common to all minerals.   This cannot be crystal structure or chemical

composition.   The concentration of gold in the more porous minerals in the
ore suggests that this factor may be the amount of surface exposed to the gold-
bearing solutions.   The mechanism of adsorption discussed in the section on
submicroscopic gold may apply to the deposition of gold in or on every mineral.
Pyrite (Fig. 26), marcasite, and carbon occur in irregular porous masses with
abundant open spaces, whereas realgar, which is more abundant than the other
three minerals, characteristically occurs in dense masses with little or no open
spaces.   As would be expected, realgar is the least important gold bearer.

During the period of mineralization, gold was constantly being carried in
solution.   In the earlier phase the solutions were too dilute to be saturated with
any gold compound, but other minerals, carbon, pyrite, and marcasite in
particular, adsorbed small amounts of this metal.   Because carbon and mar-
casite had the greatest surface, they adsorbed the greatest amounts of gold.
Gold remained in solution after the deposition of the sulfides was completed,
and the process of adsorption continued to act, forming atomic-thin layers of
gold on the surfaces of minerals around which the solutions passed.   In the
later stage of deposition, native gold was deposited in the more permeable parts
of the ore shoots where the solutions were more intense and the gold con-
centration in solution was higher.   Adsorption was no longer quantitatively
important.

The metallic bond may be visualized as a cloud or atmosphere of electrons
interstitial to the metal atoms and holding them in position in the crystal struc-
ture.   The presence of this electron cloud also brings about an attractive force
for metal ions in a solution around the growing crystal.   An adsorbed film
of metal ions contains interstitial electrons which will attract similar cations in
solution.   In this way, the thin, adsorbed film of ions may act as a nucleus of
growth of larger particles of the metal.   So in the important stages of deposi-
tion in the Getchell ore, the predominant process was one of normal metal
growth on nuclei that had been formed previously by adsorption.   The physico-
chemical conditions at that time were such that gold, no longer stable in solu-
tion, was precipitated on earlier formed gold particles.   The possible changes
in these conditions are discussed in the chapter on genesis.

Native Silver.

A mineral has been seen in many polished sections of Getchell ore which,
on account of its physical properties, is taken to be native silver.   It is white,
isotropic, and has extremely high reflectivity, considerably higher than that of
gold; it is very soft, having the same mottled, egg-shell texture that is seen
in gold.   The only mineral that fits this description is native silver; conclusive
chemical tests have not been possible, however, because the particles present are
too small.   It occurs in sizes analogous to those of gold, although megascopically
visible silver has not been found.

The ratio of gold to silver in bullion assays varies from 2:1 to 134:1 and,
for the entire bullion production, averages about 10:1.   Earlier studies of the
ore suggested that the silver probably occurs in electrum, a natural gold-silver

alloy. Only a few particles have been seen in the ore, however, and most of the silver occurs as the native metal.

The silver is probably a hypogene mineral. As the association of native silver and native gold in hydrothermal deposits is rare, the evidence favoring a hypogene origin of the silver must be critically examined. (1) In general the amount of silver in the ore varies inversely with the amount of gold. Extremely rich portions of the ore body contain less silver than the portions of average grade. There is no zonal relation other than this between gold and
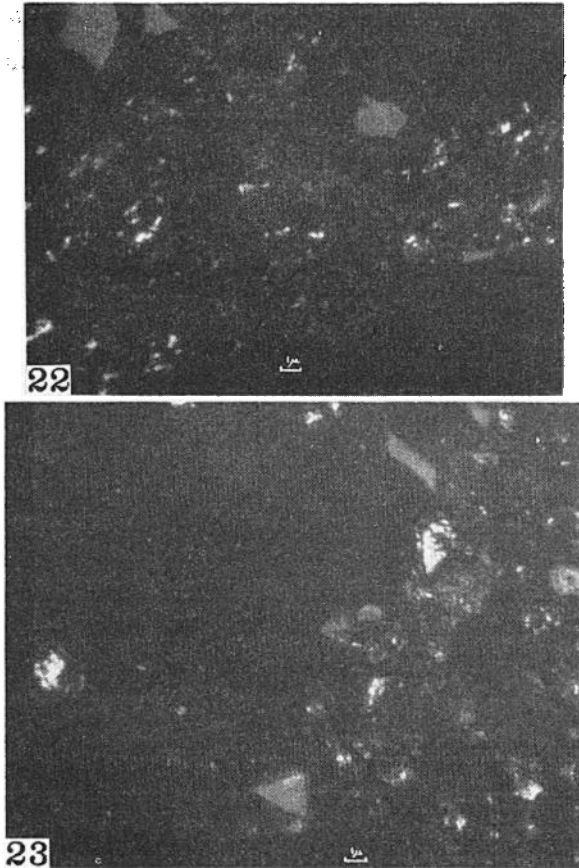

Fig. 22. Photomicrograph of gold-rich carbon veinlet. The small white particles are native gold, and the large, smooth grains are of magnetite. The indistinct gray specks associated with the gold are carbon particles. × 2,275.

Fig. 23. Photomicrograph of polished section of gold ore, showing a gold-rich lens. All white grains are gold. The gray angular fragments are magnetite and the small, irregularly rounded gray particles are carbon. The gold particle on the left is rimmed by a discontinuous halo of carbonaceous matter, as is the magnetite, bottom center. × 2,275.

silver. If silver were a supergene mineral, derived from hypogene electrum, it should be most abundant in the ore richest in gold.

(2) Native silver persists with no large decrease in amount to the deepest levels of the mine. There is no shallow blanket of richer than average silver ore, as would be expected if the silver were supergene.

(3) Silver particles show the same variations in grain size as the gold particles. If silver were supergene, formed under totally different conditions from those in which gold was formed, it would be unlikely to occur in grains of approximately the same size as the gold particles. Had silver been derived from electrum by meteoric leaching, the residual gold would be expected to occur in porous masses, but the gold particles are solid.

(4) Like gold, silver occurs in the carbonaceous matrix of the gumbo and in sulfides, particularly the porous pyrite-marcasite intergrowths. It is loosely held in the host minerals and is easily removed by rubbing. Unlike gold, silver particles do not occur in lenticular aggregates. Otherwise the habit of silver closely resembles that of the widespread but sparsely disseminated gold particles, and the periods of deposition of silver and this gold were probably overlapping.

Why silver did not more commonly unite with gold to form electrum is not clear. Gold in most low-intensity deposits contains a considerable amount of alloyed silver. At the Getchell mine, however, even the gold and silver that, on the basis of similar distribution, appear to be more or less contemporaneous occur as separate minerals, although the two may commonly be seen in the same field of view on one polished section.

A similar paradox has been noted in the occurrence of gold and silver precipitated from the cyanide solution in the milling process. Gold and silver, both carried in solution in the cyanide, are precipitated as the separate metals and not as the gold-silver alloy.

Similarly in the supergene zones of other Nevada precious metal deposits, gold and silver occur as separate minerals. Thus, gold solutions, whether naturally occurring in the earth or artificially in a cyanide tank, apparently are unable to form a gold-silver alloy. But in most epithermal gold deposits in Nevada, electrum is present. It is possible that with decreasing temperature of solution, the tendency for the formation of electrum decreases. If this is so, the temperature of ore solutions in the Getchell deposit must have been lower than those of other precious metal deposits of Nevada.

Elsewhere in the world, hypogene native silver is found in four main types of deposits: (a) associated with sulfides, silver minerals zeolites, barite, fluorite, and quartz (Kongsberg, Norway); (b) occurring with nickel and cobalt sulfides and arsenides in a calcite gangue (Cobalt, Ontario); (c) with uraninite and nickel-cobalt minerals (Great Bear Lake); and (d) with native copper and zeolites (Keweenaw Peninsula) (24, p. 98). No description of hypogene silver in minor amounts in any other deposit dominantly of gold has been found by the writer.

GENESIS.

Sequence of Deposition.

Ore deposition is a gradational process. It is not one in which the widespread deposition of one mineral stops before another mineral begins to be deposited. Any mineral will be deposited when the physico-chemical conditions are such as to make its constituents unstable in solution. It would be folly to assume that, at any one time during deposition, similar conditions existed throughout the entire area of mineralization. So a mineral that was deposited late in the sequence in one place may actually be earlier than a mineral deposited early in the sequence in another spot. Any discussion of exact sequence, therefore, must be limited to a small locality within the ore body, where similar physico-chemical conditions existed at any given time.

In general, the sequence of deposition (graphically presented in Fig. 29) of what is now the economic ore at Getchell, was as follows. Early, low-intensity solutions, being dilute, were able to do no more than locally rework the rock constituents and introduce small quantities of pyrite carrying minor gold. Coarse-grained quartz and calcite and small amounts of pyrite are the early minerals. Somewhat later, fine-grained quartz and carbon, probably derived from underlying rocks, were introduced, and were followed by the major sulfides, pyrite, pyrrhotite, arsenopyrite, and chalcopyrite. In the still later, economically important stage, marcasite, realgar, orpiment, stibnite, magnetite, gold, and silver were deposited. The period of deposition of each mineral overlapped those of several others, so these minerals may be considered as more or less contemporaneous. In any one place in the ore body, gangue minerals derived from the nearby and underlying rocks were deposited early in the sequence and metallic minerals foreign to the country rock were mainly deposited somewhat later. Most of the gold, together with silver and magnetite, is apparently the latest of the metallic minerals deposited.

In the outlying, submarginal portions of the ore body, the sequence was apparently similar to that in the now economic sections, except that the later marcasite-realgar-gold period did not appear there. Deposition in these fringing areas of the main ore body may be considered as being more or less contemporaneous with the economically important phase of deposition in the central channelways. The early, gold-poor stage of deposition in these channelways preceded any deposition in the outlying areas.

The distribution of *economic* amounts of gold is quite similar to that of realgar. There are apparently two modes of occurrence of visible gold: (1) it is sparsely distributed throughout the ore bodies, in gumbo, argillite, and limestone alike. This form of gold was deposited early in the period of formation of the realgar and these widely scattered gold particles occur in all ore that contains realgar, although they rarely occur within realgar grains. Gold of this stage probably began its growth by adsorption on carbon, porous pyrite, and in realgar only where favorable conditions existed. Silver and the rare electrum were probably more or less contemporaneous with this earlier, low-grade phase of gold mineralization as they have the same general distribution. The precious

metals deposited at this time are not to be confused with the non-commercial amounts of gold believed to be in solid solution in the earliest pyrite. To the contrary, gold of this period constitutes most of the gold in the ore bodies except the extremely local and rich shoots. (Gold of this period is illustrated in Figs. 18, 19, 20, 21.)
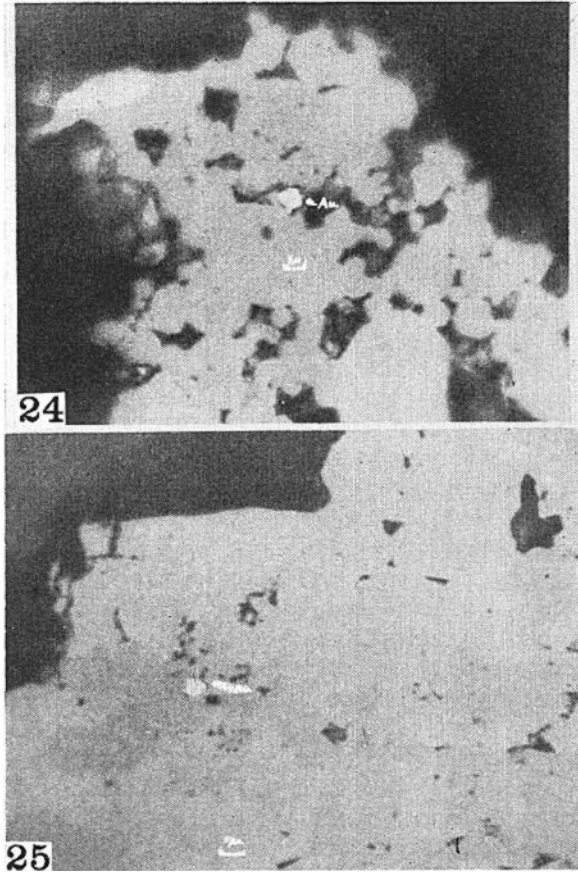

Fig. 24. Photomicrograph of polished section of pyritic concentrate, heated to 600° C, showing gold inclusion in pyrite-marcasite intergrowth. Finely dispersed gold was apparently driven to the opening in the pyrite by the heating. Note the difference in reflectivity between gold and pyrite. × 2,875.

Fig. 25. Photomicrograph of polished section of pyritic ore. The small gold grain occurs in a porous section of the pyrite-marcasite intergrowth. × 2,875.

(2) Toward the end of the period of deposition of marcasite and realgar, the most intense ore solutions passed through the few most permeable channels in the ore body which lay within the zones of abundant gumbo. A marked change in conditions of deposition must have occurred to allow the formation

of extremely rich, though small, lenses of gold and magnetite (Figs. 22, 23). Minute amounts of carbon were deposited at this time, rimming occasional particles of gold.

Summary of Sequence.—The changes in the nature of deposition with time were brought about largely by changing conditions of deposition. The changes were gradational and the minerals characteristic of the early stage were being deposited in the outlying areas at the same time that the late stage minerals were forming in the ore shoots. At the earliest stage of deposition at the known depth horizon, pyrite containing low-grade gold was deposited, with some quartz, calcite, sericite, and chlorite, near the major channelways. As the flow of hot solutions continued, more and more heat was carried into the zones of mineralization, the intensity-character increased, pyrite and lean gold were deposited farther and farther out, whereas the minerals from solutions of higher intensity were deposited toward the centers of mineralization by replacement or re-solution of those minerals that had been stable during the earlier and feebler stages then and there existing. Realgar, marcasite, and the economically important gold, which latter was becoming richer with time, were deposited in the main channelways at about the same time that the solutions in the outlying portions of the veins and wall rock were depositing disseminated pyrite and included submicroscopic gold in non-commercial amounts.

Nature of the Hydrothermal Fluid.

The hydrothermal fluid contained water, arsenic, iron, and sulfur, with minor amounts of copper, gold, silver, molybdenum, mercury, barium, and fluorine. It also contained silica, lime, and carbon, which were probably largely of local derivation. This fluid was hot, probably at a temperature of between one and two hundred degrees Centigrade. At depth it was probably alkaline, although there is no direct evidence of this. The underlying rocks contain far greater quantities of alkaline than acid elements, so, even if the solution were thought to have been acid on leaving its source, it presumably would soon become alkaline.

Transportation of Gold.—Soluble compounds of gold are not abundant. In the past, emphasis has been placed on auric chloride as the form in which gold is transported (21). However, chlorides, if present at all, are rare constituents of an ore body, especially as compared to sulfides; and even though most chlorine compounds are highly soluble and would not be precipitated, there is rarely, in any district, tangible indication that chlorine in whatever state of combination has passed through the channelways in the quantities required if the metals were brought to the place of deposition as chlorides. It seems far more reasonable to assume that the gold is transported as a soluble sulfide. Smith (27) suggested that gold may be dissolved in alkali sulfide solutions with the formation of alkali thioaurites, the general formula for which is $2Na_2S \cdot Au_2S$.

Gold is far more soluble in alkali sulfide solutions than are most metals. It belongs in the group of metals whose sulfides are highly soluble in dilute aqueous solutions of alkali sulfides at room temperature. With gold in this

group are mercury, bismuth, antimony, arsenic, and tellurium. Silver is the most soluble of the group of metals whose sulfides are soluble in aqueous solutions of alkali sulfides at high temperatures. This may explain the close spatial relation between realgar, gold, and silver, at the Getchell mine. It may also help to explain the sequence there shown, in which cinnabar, stibnite, realgar, gold, and silver are present as late minerals.

The question of transportation of gold, however, cannot yet be regarded as settled with finality, and must hopefully wait for additional experimentation and ideas. But several considerations make the thesis of transportation as double sulfides or sulfide complexes worthy of consideration for the case at Getchell.

Precipitation of Gold.—Alkali sulfides easily form double salts with certain metallic sulfides. If the sulfide concentration of sodium thio-metallic salts is lowered sufficiently, simple metal sulfides are precipitated. For gold, a reduction in sulfide content in solution causes separation as the metal rather than as sulfide, since gold sulfide is unstable at temperatures greater than 40° C (*27*).

If such a process may account for the deposition of minerals in the Getchell deposit, then there should be some evidence of decreasing sulfide ion content in solution. Orpiment, with a high sulfur content, is earlier than realgar, which contains less sulfur. This may be an indication of decreasing sulfide concentration. Pyrrhotite, pyrite, and marcasite are early and magnetite appears to be late. Laboratory experiments were carried out by the writer in which various forms of iron sulfides were synthesized from solutions at temperatures of from 400° to 600° C. The results indicate that with an excess of sulfide ions, pyrite and marcasite are formed and that with a decrease in sulfide concentration pyrite disappears and pyrrhotite is deposited. With a further decrease in sulfur, pyrrhotite, magnetite, and hematite are formed. This shift from the disulfides through the near-monosulfides to the oxides with a decrease in sulfide ion concentration is thus entirely compatible with the observed sequence at Getchell and suggests a similar decrease in sulfide concentration in the solutions as mineral deposition proceeded.

Changes in Character of Solutions During Deposition.—The presence of early calcite and pyrite and later marcasite and such sulfates as barite and possibly gypsum suggests a gradual change from alkaline to neutral and finally to acid solutions. The presence of marcasite especially indicates a change to acid solutions (1). This gradual change is not uncommon in near-surface deposits and is particularly common in fumaroles or hot springs. It essentially represents a change of sulfide to sulfate ion. This may be explained by Allen's reaction, in which free sulfur reacts with water at certain temperatures to form the sulfide ion and sulfate radical, as follows: $4S + 4H_2O = 3H_2S + H_2SO_4$. If H_2S is removed from the system, the reaction will move toward the right, bringing about a concentration of sulfuric acid which may convert the initially alkaline solution to acid.

On entering into shattered, permeable rock such as the Getchell fault zone, the ore solutions undergo loss of pressure which facilitates the loss of a gas

phase, such as H_2S, from the liquid phase. With this selective evaporation, the sulfur content of the remaining solutions will decrease as they change from alkaline to acid composition. With decreasing sulfur content and accompanying acidification, pyrite will alter to marcasite, realgar will be formed in place of orpiment, and gold will be precipitated. With further decrease in sulfur, the iron sulfides will cease depositing and magnetite will begin to form. In those environments where sulfuric acid is abundantly developed, hypogene sulfate minerals may be deposited.

If such a process has taken place at Getchell, one might question why marcasite and realgar are restricted to certain zones or shoots within the veins. This is believed related to the possibility that the hydrothermal solutions did not pass through all portions of the veins at equal rates, with the consequences discussed below. The ore-carrying solutions were probably somewhat hotter
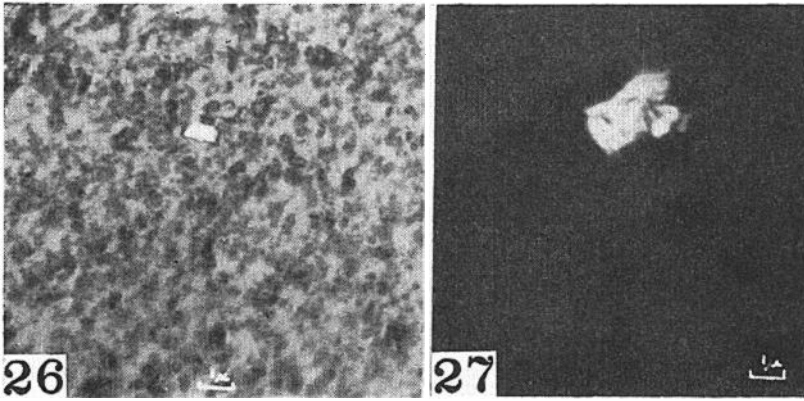

Fig. 26. Photomicrograph of polished section of pyrite. The extreme porosity was not noted under lower magnification. Some black openings are filled with quartz; many are vacant. The white grain in the center is gold. × 4,000.

Fig. 27. Photomicrograph of polished section of gold-rich activated charcoal used in the recovery of the gold in the milling process. White grain is gold, on rim of a charcoal cell. This charcoal is used because of its high adsorptive power. Compare porosity and surface to that of the pyrite in Figure 26.

than the wall rock and, during part of the period of mineralization at least, were actually heating the rocks through which they passed. As the rock became hotter the solutions could lose an increasingly small proportion of their heat. Thus, at any one point in the vein, the temperatures of the wall rock and of the passing solutions were rising and the geothermal gradient was there becoming steeper. This increase in temperature was not uniform throughout the veins, but was more marked in the loci of greater permeability through which greater volumes of the heat-carrying solutions passed. This process must not be misinterpreted to mean that any given portion of the moving solution was actually becoming hotter with time; it was simply cooling at an increasingly small rate, and therefore was followed by portions of solutions progressively hotter.

So within the veins there were hot, permeable loci separated by less permeable and cooler places. The separation from the solution of H_2S in the gas phase would be favored by a sufficiently high temperature to keep up its production by the Allen reaction cited above, and by a pressure so low as not to retain
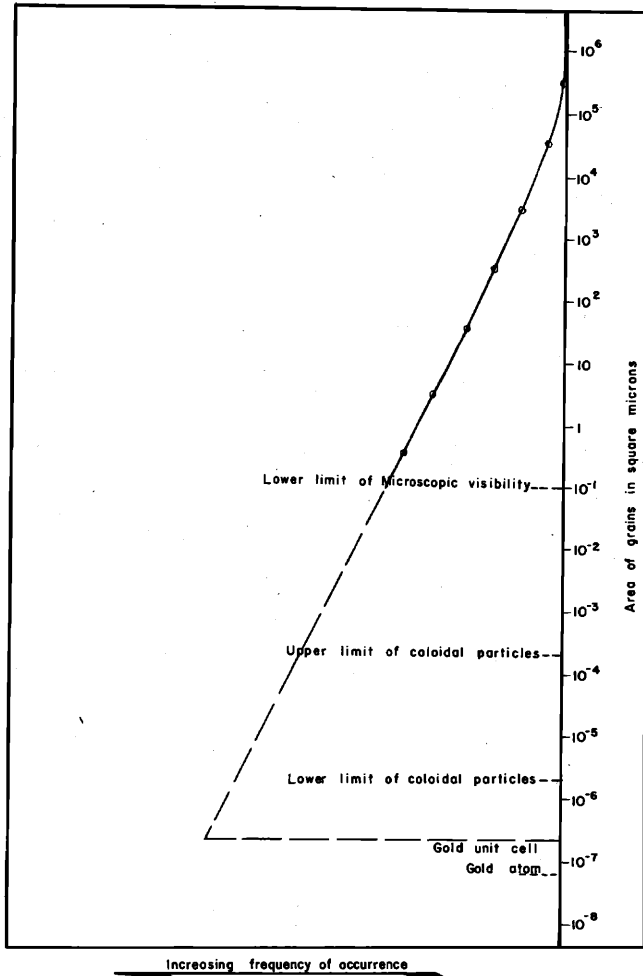

FIG. 28. Frequency distribution of gold grains, showing probable extension in submicroscopic range. A logarithmic scale is used on the abcissa.

the H_2S in solution. Such rather special combination of temperature and pressure would be most probably along the more permeable and hence hotter axes of flow.

Thus the ore solutions probably remained alkaline in the less permeable portions of the veins while they were becoming neutral or somewhat acid in

the hotter ore shoots.   Pyrite was deposited throughout the veins in the earliest, alkaline period of deposition, and only in the lower-grade, less permeable and cooler sections during later stages of mineralization.   Realgar, marcasite, and the richer occurrences of gold were restricted to the hotter parts of the veins where the solutions were neutral or acid.   The gold, realgar, and magnetite were deposited from hotter solutions than those that formed the pyrite and the conventional gangue minerals.

In the past there has been a tendency on the part of geologists to assume that the terms "low-temperature mineral" and "late mineral" are synonymous. Graton (11) has questioned the validity of this reasoning, and recent work at Butte has indicated that late minerals were actually formed at higher temperature and under conditions of higher intensity than the early minerals (26).

Further evidence in support of such relations of temperature and sequence is found in the Getchell deposit.   The early solutions were apparently dilute and undersaturated with the ore minerals.   These solutions were able only to redistribute the rock minerals within their respective beds because they were already considerably depleted in intensity, and could only transport dissolved material a few inches.   Those portions of the later solutions that were able to remain within the more permeable loci in the veins, benefitting by the heating already accomplished there, were able to do a more "intense" kind of work. Gangue minerals in these favored portions were no longer so localized, and quartz replaced limestone, argillite, and andesite with about equal ease.   In place of the early, coarse-grained quartz that was deposited in a leisurely manner from dilute, alkaline solutions, the fine-grained quartz was formed by more rapid growth from relatively concentrated and probably acid solutions. The earlier, euhedral pyrite gave way to the later, irregular pyrite-marcasite intergrowths that probably represent deposition from more concentrated and hence more intense solutions.

Age of Mineralization.

The Getchell ores were deposited at some time subsequent to the intrusion of the andesite porphyry, which is tentatively dated as early or middle Tertiary. A period of silicification to form the opalite occurred after deposition of the rhyolite tuff.   The strongest mineralization in the Getchell ore bodies occurs toward the north end of the mineralized zone nearest to the deep pipe of rhyolite tuff.   It is possible that the ores are later than the rhyolite and represent a late phase of that period of igneous activity.

The Getchell ore body is similar in many ways to the gold-realgar deposits at Manhattan, Nevada, about 150 miles to the south.   At Manhattan, both early andesite and late rhyolite dikes occur near the ore body.   In the description of this deposit, Ferguson (8) suggests that the gold mineralization may be post-rhyolite.   He points out that at Round Mountain, 50 miles north of Manhattan, gold ore containing realgar occurs in a rhyolite plug and is therefore later than the rhyolite (7), and that these two deposits may belong to a post-rhyolite period of mineralization.   The close parallelism in the character

of the Getchell and Manhattan deposits suggests that they may belong to the same general period of mineralization.

In his description of the mining camps of Nevada, Ferguson (9) shows that the Tertiary precious metal deposits in that area may be divided into two groups of widely differing character. In the older group the deposits are generally more persistent laterally and vertically. They all contain manganiferous calcite and have a ratio of silver to gold greater than 1 :1. In the other group, gold is generally present in larger amounts than silver and the structures are less persistent. Goldfield, type example of this group, has a gold-silver ratio of 7 :3.

Realgar is not found in most of the gold-rich deposits. In those in which it is found, Getchell and Manhattan, the bullion reports indicate the great preponderance of gold over silver, the gold-silver ratio varying from 10 :1 at Getchell to 17 :1 at Manhattan. It is possible that this type of ore deposit, characterized by a very high gold-silver ratio and the presence of realgar, may represent a third, still later group of deposits formed in late Pliocene or early Pleistocene time. These deposits have many features in common that are not shared by other late Tertiary gold ores. Both contain realgar, orpiment, cinnabar, carbon, stibnite, fluorite, and pyrite. An unusual green calcite is found in each. Silver sulfides or sulfosalts are lacking. At both deposits the gold is very fine-grained and is closely related spatially to realgar and carbon. In each, lead, zinc, and copper sulfides are rare or nonexistent. Both contain relatively large replacement bodies that are more important than the single narrow fissure veins.

Ferguson (8, p. 106) suggests that the high gold-silver ratio may be due to the presence of arsenic minerals. He proposes the theory that hypogene solutions rich in arsenic and free from lead, zinc, and copper tend to precipitate gold without any important mixture of silver. There appears to be no chemical basis for such a reaction and the common occurrence of gold-poor proustite deposits would seem to disprove this theory. Butler (5) gave a more plausible explanation, suggesting that the presence of carbon may be important in bringing about a high gold-silver ratio, as carbon is known to precipitate gold selectively from a gold-silver solution. Carbon is undoubtedly important in precipitating larger amounts of gold, but there may be a simpler explanation of the high gold-silver ratio.

Hydrothermal solutions, on rising, may be expected to change gradually from alkaline to some degree of acidity. As a consequence, gold will tend to be deposited as soon as sufficient sulfide ions are removed, but silver sulfides and sulfosalts, being soluble in acid solutions, will no longer be deposited but will be swept along the channelways. The sulfuric acid will gradually be lessened in the course of this journey, partly through the precipitation of sulfates and partly by reaction with sericite and feldspars to form clay minerals. When and where the acidity becomes sufficiently lowered, the silver-sulfur compounds could again be precipitated to form a shallow silver zone capping the gold.

It is possible that the solutions might reach the surface before adequate reduction of the acid had occurred. In such a case, the resultant deposit

would consist only of a gold zone. Getchell, Manhattan, and Goldfield may be examples.

There are gradations in the character of the deposits of from middle to late Tertiary age (i.e. Tonopah, Goldfield, Manhattan, Getchell) and it is probable that the entire late Tertiary period was an epoch of continual mineralization.
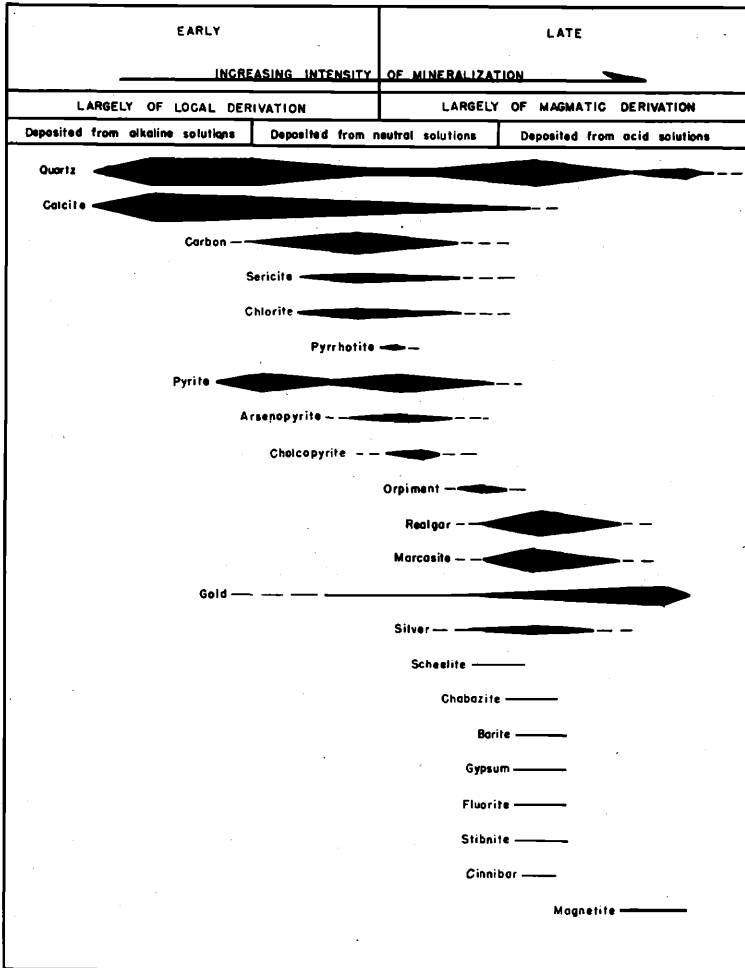

FIG. 29. Sequence of deposition of Getchell ore minerals.

The changes in character of these deposits may be explained by the fact that decreasing age has permitted an increasing escape from erosive removal of the shallowest portions of the initial deposits.

The similarities between the Getchell and Manhattan deposits have been discussed previously. There are, however, certain discrepancies between the

two deposits. The presence of adularia in some mines at Manhattan suggests that it may represent a slightly more intense phase of mineralization. Native silver as a hypogene mineral is not reported from Manhattan and, if the presence of native silver together with native gold is an indication of lower intensity, the lack of silver at Manhattan corroborates the other evidence favoring higher intensity for that camp.

A feature of the Getchell deposit that sets it apart from the typical epithermal gold deposits is the nearly complete lack of certain common epithermal structures such as "colloform" banding, crustification, and comb structure. This suggests that the Getchell deposit may be intermediate in character between the typical epithermal precious metal and the quicksilver deposits. Many of the quicksilver veins of Nevada show a close relationship to both the gold-silver and stibnite-realgar types of deposits (20, p. 473). The deposits at Steamboat Hot Springs, located a few miles south of Reno, contain some cinnabar and show many striking similarities to the Getchell deposit. At Steamboat as well as Getchell, Tertiary igneous activity is represented by early andesite and late pumiceous rhyolite. The rhyolite at Steamboat is Pleistocene or recent, a fact that may suggest a Quaternary age for the Getchell rhyolite tuff. Silica in the form of opal, chalcedony, and fine-grained quartz is abundant in each deposit. According to Brannock et al (4) the Steamboat waters contain a mud which is largely composed of tiny particles of opal or a silica gel. This mud apparently closely resembles the Getchell gumbo, and its other features strengthen the resemblance. Minute acicular crystals of stibnite occur in the mud and have also been found floating as a thin scum on the surface of the waters of the spring. These fine-grained aggregates of stibnite needles closely resemble the unusual felt-like stibnite crystals from the Getchell ore body. Pyrite and realgar have been identified in the Steamboat mud, and the presence of an iron oxide, possibly magnetite, is suggested. The most striking feature common to the mud and the gumbo is the presence of gold. Two of the most important wells at Steamboat contained mud with between 0.3 and 0.4 ounces of gold per ton. The ratio of gold to silver in these muds is 1 :3. Copper is present in the muds, as in the Getchell gumbo, in extremely small amounts.

The siliceous sinter at Steamboat contains pyrite, arsenopyrite, stibnite, and some cinnabar. The sinter is stained in places with a red-brown antimony ochre, metastibnite; ilsemannite has also been found.

These features strongly suggest a very close genetic relation between Getchell and Steamboat Springs.

Figure 30 shows the location of the major deposits of Nevada in which either cinnabar or gold is the economic mineral. The important cinnabar deposits lie in a relatively narrow, northerly trending belt that cuts the west-central part of the state. The chief gold deposits, on the other hand, show no regularity of distribution, but are widely spaced throughout the entire state.

The Great Basin is composed of a series of northerly-trending structures, both folds and faults. Even the recent faults (10) trend in a northerly direction. Most of the cinnabar deposits are relatively young, and all are probably Pliocene or later. It is possible that a major late Tertiary belt of faulting is

now marked by the larger cinnabar deposits shown in Figure 30. Such a belt would act as a locus for the cinnabar-depositing solutions.

Nolan (23, p. 152) has described a geanticline that divided the Paleozoic geosyncline, persisting from late Devonian to early Permian time. The axis of this geanticline is shown in Figure 30. It may be merely coincidence that most of the larger cinnabar deposits and the Getchell ore bodies lie along or near this axis, as the period of geanticlinal deformation was over by Permian
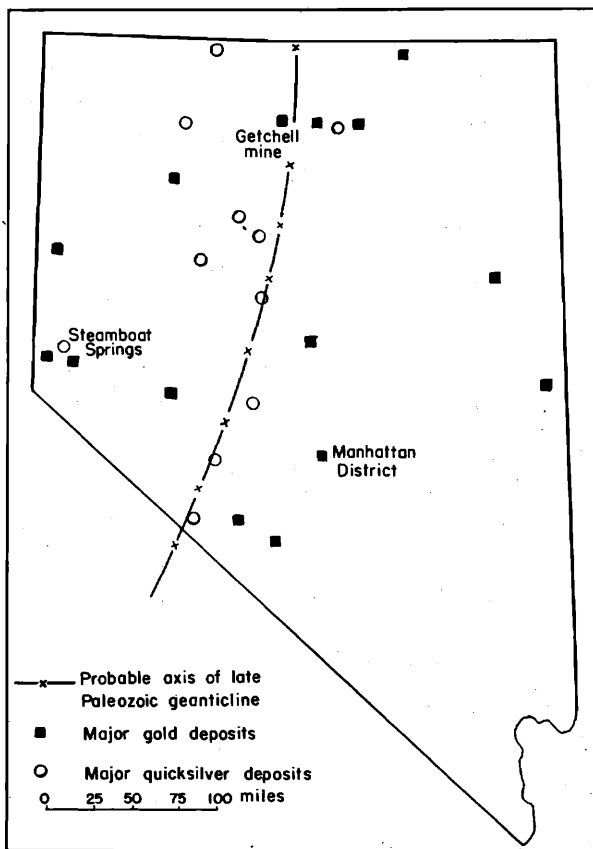

FIGURE 30 MAP OF NEVADA SHOWING LOCATION OF
MAJOR GOLD AND QUICKSILVER DEPOSITS

time whereas the gold and cinnabar deposition was late Tertiary or early Quaternary. It is nevertheless possible that the geanticlinal axis was and has continued to be a zone of weakness along which later, deep-seated faults have formed from time to time. Along such faults, mineralizing solutions could rise to deposit cinnabar or gold.

The Getchell mine is located within this cinnabar belt, near its eastern margin. The Manhattan deposits lie slightly east of this belt. It may again be

coincidence that these two gold occurrences lie near or within the belt, but their mineralogic and textural features suggest a genetic relation to cinnabar deposits. It is probable that the Getchell and Manhattan gold deposits represent a gradation between the earlier gold ores such as Goldfield and the more recent cinnabar deposits.

A period of mineralization may thus be considered to have begun in middle Tertiary time with the deposition of silver-gold ore bodies, gradually changing in character to form the deposits in which gold slightly exceeded silver. Somewhat later the arsenical Getchell-Manhattan type was formed, with gold far outweighing silver, and with cinnabar present in small amounts. The Getchell and Manhattan deposits apparently may be regarded as a link toward bridging the gap between the precious metal and the mercury deposits. In the latest important stage of this period of mineralization, the cinnabar ore bodies were formed. The final dying stage of mineralization is represented by Recent hot spring deposits. Many of these are similar in character to the cinnabar deposits, but a few, such as the Golconda tungsten-manganese blanket (17), are completely different. The hot spring deposits presumably represent a less intense phase of the same period of mineralization that formed the cinnabar vein merely because the former are shallower. The variation in intensity would include changes in temperature, pressure, and particularly in concentration. Regarding the possibility of a protracted epoch of Tertiary mineralization, Lindgren said, "This whole process of metallization, beginning at the earliest Cretaceous, closing at the end of the Tertiary, and feebly continuing today, is actually one continuous operation of separation of volatile constituents from the magma . . ." (19, p. 179).

Depth of Formation.

The Getchell ore bodies were formed under a relatively shallow cover. The large vugs in the ore and the intensely shattered nature of the ore zone are the best evidence favoring deposition in a shallow environment. The plastic, unconsolidated character of the gumbo likewise suggests a near-surface origin. As relatively thin outliers of rhyolite tuff still remain near the ore zone, it is probable that erosion has not removed more than a few hundred feet of rock since the deposition of the rhyolite.

The apparently close affiliation between the Getchell mineralization and the cinnabar deposits suggests that they were formed under somewhat similar conditions. Bailey stated that the opalite type of cinnabar deposit was probably formed at depth of about 500 feet beneath the surface (3, p. 20). The present tops of the Getchell ore bodies were probably deposited within a thousand feet of the then-existing surface.

Genetic Classification.

The Getchell ore bodies are clearly epithermal as outlined by Lindgren (20). They constitute a particular and self-characteristic example, a narrow subdivision of the broader epithermal class. The Getchell deposit belongs

among those that represent the least intense portion of the epithermal class. Graton, in proposing the telethermal depth-zone (11, pp. 547–551), has suggested that the epithermal deposits do not represent the very lowest intensity end members of the hydrothermal family. He points out that certain low-intensity stibnite-realgar and cinnabar deposits may be a gradational form between typical epithermal deposits that are characterized by relatively rapid deposition and telescoping because of steep thermal gradients, and still feebler telethermal deposits formed by leisurely deposition in a cooler environment.

Despite its many unusual features, the Getchell deposit must be considered as epithermal on the basis of the telescoped nature of mineralization. It has been suggested that this deposit may represent a gradation between the typical epithermal precious metal and the cinnabar deposit. The increasing differences from the progressively older and somewhat deeper-lying precious metal deposits and the growing evidences of similarity with the cinnabar deposits progressively closer to Getchell in youth and shallowness, place the Getchell deposit close to the feeblest end of the epithermal group. It may well be that hot-spring sinters were formed at the surface only a few hundred feet above the present vein outcrops.

PARK CITY, UTAH,
   Nov. 3, 1950.

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