GEOLOGY and ORE DEPOSITS
of the
TWIN BUTTES DISTRICT

by
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INTRODUCTION.

Location and Extent of Region.

The Twin Buttes Mining District is 26 miles south-southwest of Tucson, Arizona. It is reached by a good road from Tucson through the Mineral Hill and San Xavier camps. This road continues on connecting with the main highway to Nogales just southwest of Continental. Besides this road there are several unimproved desert roads to Twin Buttes from the main road in the vicinity of Sahuarita. The district is also connected by railroad with the Southern Pacific at Sahuarita. Ore trains are run once or twice a week and return with water for the village which is just N. of the depot and mine office. Most of the inhabitants are Mexicans, the majority being employed in the mines of the vicinity. The area covered in this report comprises a strip two and one-quarter miles long and averaging half a mile wide running in a northeast-southwest direction just south of the settlement. It includes all of the important mines and large prospects in the immediate vicinity with the exception of the Barconi Lead-Silver Mine southeast of the Senator Lorgan.

Field Work.

Field work covered a period from the fall
of 1925 until the spring of 1926 during which an average of two days a week were spent at Twin Buttes. With the assistance of Mr. North and Mr. Spooner an accurate base map was made by stadia methods. The areal geology was placed on the base map by intersection method using an open sight alidade, Gurley compass, and plane table. A large portion of the latest work done was underground examinations of the mines, the Queen, Glance, Senator Morgan, North Star, Minnie, Gladstone, and Bullion being visited. The Glance was the only mine mapped in detail, it being the only active producer in the district.

In conjunction with the field work trips to the north side of the Catalina Mts., Picacho de la Calera, the southern Tucson Mts., the Sierrita Mts., the Santa Rita Mts., and the Mineral Hill, San Xavier and Olive Camps were made to compare and correlate the formations at Twin Buttes with those in these neighboring districts.

Previous Work and Acknowledgments.

In a paper entitled "Ore Deposits of Sierrita Mountains, Arizona," pages 407-428, Bulletin 725, U.S.G.S., 1921, F.L.Ransome gives a reconnaissance report of the Twin Buttes District. The district was visited at a time when all the mines were closed down but an accurate broad description of the conditions is given. E.R.Gordon in a ten-page thesis bound in University of Arizona library, has a rough sketch map, two views and a very brief description of some of the

In the preparation of this paper valuable assistance in the form of suggestions and criticisms was received from members of the Department of Geology and of the Arizona Bureau of Mines, University of Arizona. The underground work at the Queen Mine was made possible through Mr. William Foy, general manager, and Mr. Ed. Foy, superintendent of the Midland Copper Company. Mr. William Symington, Mr. Jim Ritchie, and Mr. McAllister, all of the Midland also extended every courtesy. Mr. J. Kruttschnitt of the A.S. and R. kindly went over conditions at the Minnie with me. Mr. F.M. Murphy assisted in the preparation of thin sections, Messrs
Fig. 1. View of the Twin Buttes Mining District from the north.
North and Spooner in the preparation of the topographic map. Mrs. Julia Baxter was the source of much of the early history of the district. Mr. Roy Shimer of Minneapolis, Minn. was helpful in explaining the status of the different companies and claims in the district.

MINING.

History.

In 1895 the first claims in the Twin Buttes District were located by Mr. Baxter, who had up to the time of the demonitization of silver been active in the Olive Camp. He worked upper portions of the Senator Morgan and Copper King ore bodies until 1903 when the Twin Buttes Mining and Smelting Company under the head of Mayor Rose of Milwaukee took over the property. Mr. Baxter remained in charge of the mining operations which were carried on principally at the Senator Morgan Mine. In 1905 twenty-eight miles of standard gauge track was laid between Tucson and the Senator Morgan Mine. The mine was actively worked until the early part of 1907 and the gross production was in the neighborhood of one million dollars. At this time Mr. McDermott was placed in charge and production continued for eighteen months. The mine was then closed down until 1910 when Mr. James Higgenes of Butte, Montana took it over and operated for two years. Following this Mr. Waters had charge of the Senator Morgan for a year and then Mr. E. G.
Fig. 4. Original surface workings on Senator Morgan claim showing adit on NE-SW fault zone.

Fig. 5. Original tunnel on the Copper King claim.
Bush worked it under a nine-months lease after which it was closed down and has remained so up to the present time. The mine was first worked through a three-compartment shaft sunk on the surface garnet zone and later through a two-compartment shaft to the southeast. Mining was carried to a depth of 855 feet where the ore is said to have become of too low grade to work.

During the time that the Senator Morgan was being worked other mines, including the Glance and the Queen were opened up, but not actively developed. In 1914 Bush and Baxter mined $200,000 worth of ore from the Minnie Mine and then leased it for $400,000 to the American Smelting and Refining Company who operated it until 1916 when it was closed down due to bottoming of the ore. The claim is now held by Mr. William Foy but no work has been attempted on it since that done by the A.S. and R. In 1916, Mr. Ed. Bush and associates took a lease and option on the Glance and operated it for three years with a net production of $235,000 which was not enough to pay for the $300,000 bond required. The year following their lease on the Glance Mr. Bush and associates took a lease on the Queen which was operated until late in 1919. During 1920 and '21 it was closed down and then re-opened and unwatered in August, 1922 by the Midland Copper Company which has continued mining to the present.

Among the smaller mines of the district the
Fig. 2. Senator Morgan Mine with head frame of the new Gladstone shaft in the background.

Fig. 3. The Copper Queen and Copper Glance Mines from the northeast.
North Star is the oldest. Little work, however, was done until in 1919 when the shaft was sunk to its present depth of 210 feet and several crosscuts from both the 210 and 150 level were run into and through the garnet zone. Ore was struck but none has been shipped. About the same time the Butte inclined shaft just west of Twin Buttes was sunk and ran into granite with some mineralization at a depth of 85'. Last year the Bullion shaft on the southeast of Glance Hill was sunk to a depth of 215 feet and since then has been carried deeper by a winze. The Gladstone was started late in the year and has been actively developed since. Numerous prospects have been opened up from time to time, several of the larger and more important ones being on the claims of Mr. John Latz of Tucson.

Present Activities.

The Midland Copper Company owned principally by Mr. J. R. Ricketson and Mr. Feister of Milwaukee and Mr. William Foy of Twin Buttes is at present the only company operating in the district. Mr. William Foy is general manager of the company and Mr. Ed. Foy is superintendent of the mines. Sixteen claims are owned by the Midland and a number of others leased from the old Twin Buttes Mining and Smelting Company, including the Glance and Gladstone. The Queen which was purchased from the Twin Buttes Mining Company, is the only productive mine and is being worked from the 440 to 700 foot levels. Since 1922 there has
been mined on an average of 1800 tons of copper ore per month yielding 200,000 lbs. of copper and 3500 oz. of silver. In 1925 18,698 tons of ore were mined giving 2,407,811 lbs. of copper and 37,489 oz. of silver. The ore averages over 6% copper and nearly 2 oz. of silver to the ton. The Midland have a smelting contract with the A.S. and R and the ore is sent either to Hayden or El Paso. Shipping ore is made up of a mixture of the high and low grades from the mine.

During the past year the Glance Bullion shaft was sunk 315' on the southeast of Glance Hill and the working carried 100' deeper by winze. Low grade copper ore was found at this depth and it is the intention of the company to diamond-drill at the Bullion in the near future.

On the Gladstone claim, the new Gladstone shaft has been sunk 400' since late in 1925. Five drifts are being run in different directions.

The Midland Copper Company delivers all its ore to the Southern Pacific at Sahuarita having purchased the portion of the railroad between Twin Buttes and Sahuarita from the Twin Buttes Company. Prior to this the Southern Pacific purchased the track between Sahuarita and Tucson and since have extended it into a main line to Nogales. Shipments are made once or twice a week, the Company operating its own locomotive and a number of ore cars.
Mining Methods.

The main portion of the ore being mined by the Midland Copper Company at the Queen is heavy massive sulphide. The bodies are of irregular form and are in garnet or between it and massive limestone. These conditions make it possible to mine most of the ore without any timbering. The open stope method is used, the ore being hand sorted and mucked to raise chutes or into cars and run to the level loading pockets. In the east end of the mine there is considerable shattering near the footwall of the deposit and portions of the drifts in this region require timbering. The ore on this side of the mine is oxidized or partially oxidized from the surface down to the bottom level and in places stubs and small bulkheads have been used to hold the hanging wall. In some of the large stopes in other parts of the mine large bulkheads have been built to hold waste from the top of which prospecting and mining of the crown of the stope is carried on. Ordinarily the ore bodies are mined by simple overhead stoping working on the top of the broken ore. In some cases the ore along the hanging wall is mined upward and that along the foot downward. The Queen is connected with the Glance by a tunnel on the 600-foot level. The Glance vertical shaft is used for raising and lowering men, the Queen inclined shaft for the removal of ore and waste by skips.
Topography.

The Twin Buttes Mining District is on the east side of the Sierrita Mountains five miles from their base. The main topographic features of the district are a group of hills which rise 125 to 200 feet above the piedmont plain which slopes from the mountains toward the Santa Cruz River six miles to the east of Twin Buttes. Of these hills all the more important ones with the exception of El Pie have an east-southeast trend which in a general way is roughly parallel to the bedding of the sediments of which they are made up. The north-south axis of El Pie Hill may be due to the faulting of resistant material in that direction. Minor hills in the main igneous area strike in all directions and in the main are the result of dikes. On the north about a mile distance are two fairly high hills called the Twin Buttes and to the east of these are two low hills. West of the district across a deep wide wash and valley is another group of hills that appear to rise 500 feet above the general level. These hills together with those in the district constitute a feature not common in the basin and range province of Arizona where as a rule the piedmont plains rise gradually to the base of the mountains which have
steep slopes to their summits. The highest point in the
area mapped is 2720 feet above sea level and the lowest
elevation is 3319. These elevations and elevations assigned
the contours are based upon a datum of 3441.5 feet for the
collar of the Queen shaft, being the average of several
readings taken with a Paulin altimeter set at the bench mark
in the southeast corner of the courthouse square, Tucson.

Drainage.

There are no permanent streams in the district.
The occasional and sometimes frequent rains many of which are
heavy downpours result in large run-offs. The water is carried
in arroyos which spread out into wide sand washes to the east
and with many minor flexures have a trend parallel with the
axis of the main hills. Eventually these washes drain east
and northeast to the Santa Cruz River. Mines in the eastern
part of the district such as the Queen and the Glance have
but little water to contend with, while at the Gladstone
pumping constitutes a serious problem. The water in the
abandoned mines on the west is at a high level also. This
condition suggests that the various areas of the sedimentary
rocks of the ends of the district are not connected in any
way, a fact borne out by the surface exposures.
Climate.

The region is a desert with a warm arid climate. The mean annual temperature is about 63° and the average rainfall about 13 inches a year. The winters are mild and the summers quite hot with the maximum range of temperature in the vicinity of 100° from 10° in the winter to 110° in the summer. The daily range is also large running from 35 to 50°. July and August are the rainy months with occasional rainy early springs. However, on the average the weather is clear and dry, the percent of clear weather being about 85% of that possible and the annual average humidity 45%. This latter makes the high summer temperatures less oppressive.

Vegetation.

The seasonal concentration of rain and high temperature give the region a considerable desert flora. Among the trees are the mesquite (Prosopis velutina), palo verde (Parkinsonia microphylla) which are thorny legumes and the Ocotillo (Fouquieria splendens). The cacti are the most widespread of the flora and the most impressive. They include the sahuaro (Carnegiea gigantea), cholla (Opuntia mammillata) and prickly pears of the same genera. The yucca and the century plant are members of the lily family adapted to a dry climate. All of these forms have sharp spines and in some cases recurved.
The fauna includes numerous rabbits and small rodents, and a few coyote, lynx and fox. The common birds are the buzzard, raven, and quail, with some roadrunners and turtledoves together with smaller desert species. The poisonous forms of life encountered include the Gila monster, rattlesnakes, tarantula, scorpion, and centipede.

SEDIMENTARY ROCKS.

Pre-Carboniferous.

The lowest member of the sedimentary series found in the district is a quartzite of probable Cambrian age. It is underlain by a coarse grained granite and above it is a shaly limestone. Surface exposures vary considerably in size probably due to a number of causes among which faulting appears to be the most important. Overlap and changes laterally in sedimentation may also in part be the cause of such variance in exposed thickness. On El Pie Hill a belt of quartzite runs along the southern flank averaging about 400 feet in width while the northern knoll is all quartzite. Similar conditions prevail on the Minnie hill where there is a band of quartzite 300 feet wide along the south and on the main hill at the northwest. Smaller exposures of quartzite are found across the railroad to the southeast of El Pie hill and in the western part of the area.
where it lies in patches along the east and north of the sedimentary rocks.

On weathered surfaces this quartzite varies from a pale orange color to a very dark gray in the more shaly portions, and has a smooth and in the case of the lighter portions, a somewhat vitreous appearance. It is made up of rounded and sub-angular grains and in general is poorly sorted. At the base the quartzite is quite arkosic containing some grains up to a quarter of an inch in size. This grades upward into the typical medium grained portions and then into the rather fine grained shaly quartzite. Fresh surfaces of these different parts show the arkose as mottled brown and gray, the medium grain portion as a mottled light gray and the shaly portion as a mixture of black and gray grains. These characteristics indicate moderately shallow water deposition not far from the source of the material. Such conditions would be afforded by an epeiric sea.

Apparently conformable above the early quartzite is a shaly limestone that is pre-Carboniferous and may be of Cambrian or Devonian age. It outcrops in the eastern part of the district forming a belt averaging 470 feet along the north side of the early quartzite. No definite exposures of this limestone were found in the more broken sedimentary area to the west but conditions seem to indicate that a portion of the area south of the quartzite belt is underlain by it.
The occasional outcrops of this limestone have a dull gray and thin bedded appearance. There are a few beds of fairly crystalline limestone, but in general silicification of both the calcareous and argillaceous beds is the rule. Silicification is especially conspicuous in the vicinity of Minnie Hill. Beds of shale both thin and moderately thick are numerous, and the major portion of the limestone is quite shaly. Fresh surfaces show alternating light and darker gray beds due to varying amounts of argillaceous content. The character of this limestone suggests epiergic sea deposition under a greater depth of water than prevailed when the underlying quartzite was deposited.

**Carboniferous.**

The most conspicuous formation of the district, a massive gray-white limestone is placed in the Carboniferous. It forms Glance and Queen hills on the east and portions of several minor hills in the western part of the district. The maximum thickness exposed is 1340 feet on Queen Hill, other outcrops varying from 1000 feet down to narrow belts left by erosion or faulting. It is apparently conformable above the early shaly limestone.

The greater portion of the Carboniferous limestone is recrystallized to a massive marble. From a distance the hills composed of it appear as white domes. Closer it is seen to be composed of thick beds largely re-
crystallized, varying in color from gray-white to medium dark gray. At the base it is composed of crystals of varying size up to 6 mm. and has a sugary texture, being easily dug out with a pick. This portion of the Carboniferous may be of Mississippian age. Above this are alternating thick beds of more compact and in general thoroughly marblized limestone of varying color containing bands of metamorphic minerals, nodules of chert, and in places a network of calcite veins. In one of these beds somewhat darker, finer grained and far less recrystallized than the rest Mr. Woodell found fossils identified by Dr. A.A. Stoyanow of the University of Arizona as Lophophyllum proliferum (M.E. & H.), a Pennsylvanian coral. There are numerous fragments of other fossils all too poor to identify. Character and fossils indicate marine deposition at a moderate depth.

Post Carboniferous.

Shale is found dipping away from Carboniferous limestone and apparently overlying it in the western part of the area. There are fair exposures along the wash to the north of Senator Morgan Hill where there seems to be a slight unconformity between it and the Carboniferous. On the other hand the sediments appear gradational in character. To the northwest of the exposure along the wash the shale seems to have been faulted out in part or to thin rapidly. It was not
noted on the portion of the hill extending in that direction the post carboniferous quartzite apparently being in contact with the Carboniferous limestone. This shale may be of Cretaceous age.

Not very resistant to erosion compared to the rocks it is associated with, the post Carboniferous shale tends to be obscured. Weathered surfaces vary considerably in color but tend to be lighter than the average shale. It is especially light colored toward the base, this portion being highly calcareous. Toward the top it becomes thinner bedded with intercalated layers of quartzite. At the extreme eastern exposures mapped portions have been recrystallized to hornfels which forms rather steep embankments along the wash. Conditions of deposition appear to have been under fairly shallow water with frequent fluctuations of depth.

Overlying the post Carboniferous shale is a thick quartzite formation which comprises the surface rock of Morgan Hill. It extends down the southwest slope of the hill nearly to the base where it forms an irregular contact with an intrusive granite.

The weathered surface of the quartzite has a dull granular appearance and is buff colored with more greenish areas here and there. It is well stratified and composed of fairly well sorted grains. Cross-bedding was noted in several places. On fresh surfaces the color ranges from light greenish gray to dark gray. It is quite fine
grained and the greenish hue is due to varying amounts of epidote up to about one half the rock. The bedding is fairly thin and there are a number of interbedded strata of shale. Conditions of deposition seem to have been somewhat similar to those under which the shale was deposited with the water somewhat shallower and less fluctuation of depth.

Quaternary.

Deposits referred to the Quaternary period occupy the surface at the base of Glance Hill and nearly surround Queen also. From these hills conglomerate and alluvium are the surface rocks for considerable distances in all directions except to the west. Quaternary alluvium also covers the surface about the larger washes. Portions of the west central granite area near its southern border are covered by conglomerate to a considerable depth in some places.

The Quaternary in large part consists of poorly consolidated or unconsolidated conglomerate composed of coarse stony detritus, gravel and sand. Many of the boulders are of large size and the larger portion appeared to have come from the granitic area to the west. About the base of many of the sedimentary hills fragments of the country rock cemented by calcite form small areas of caliche. In general the caliche appears to be more consolidated and younger than the conglomerate further from the hills. Beside these deposits shallow superficial deposits of fine
sand occur in the bottoms of the washes. Apparently the Quaternary was formed by a long continued period of erosion and perhaps lacustrine conditions in some of the main valleys.

IGNEOUS ROCKS.

Pre-Carboniferous.

A coarse grained dark gray and brown appearing granite occupies a large area in the west central part of the district. It also is found on the northwest of Minnie hill and along the south base of El Pie hill. It seems to underlie the pre-Carboniferous quartzite although the contact is very unsatisfactory for the determination of the true relations. Its relation to the other rocks of the district seem to indicate that it is pre-Carboniferous and its lithologic character suggest that it is pre-Cambrian. It includes various other rocks such as schist, diabase and limestone and is cut by numerous dikes most of which are aplitic and coarse grained. Apparently none of these cut the pre-Carboniferous quartzite. Its coarse texture and gneissic structure suggest that it is an older granite than the others in the region. On the other hand fresh specimens from shafts sunk in this granite yield a gray rock which is quite similar to the granite intrusive into the limestone of Queen hill. Also, the surface granite north of the Butte shaft which has been grouped with the earlier post-Carboni-
Fig. 6. Microcline Granite showing secondary quartz between primary quartz and microcline which is thoroughly altered except for a few clear areas. A portion of the dark area was made up of finely divided mica and nearly opaque.

Fig. 7. A dike rock north of the Gladstone shaft showing what appears to be a micrographic intergrowth between quartz and microcline.
ferous intrusive weathers in much the same way as the older granite. A change in the classification of this pre-Carboniferous granite to post-Carboniferous would make all the sedimentary rocks of the district floated blocks but would not materially change the age relationships. Such a classification under the existing field evidence and difficult microscopic investigation would be hard to support.

Under the microscope thin sections from various parts of the area mapped as pre-Carboniferous granite show microcline, microperthite, quartz, biotite and muscovite as the principal primary minerals with magnetite accessory. There is secondary quartz and chlorite and the alteration products are sericite, kaolin and limonite. In some sections a small amount of andesine feldspar was seen and in several cases what appeared to be leucoxene was associated with ilmenite in diamond shaped crystals. In the sections from the more gneissic portions the biotite and muscovite were crushed to small plates and into the interstices between the more competent feldspar and quartz. Secondary quartz and chlorite often follow these crushed mica areas. Considerable secondary pyrite was seen along the quartz veins in some of the specimens. The microperthite was so coarse in some cases that it could be seen under plane polarized light. Most of the microcline was thoroughly altered with occasional remarkably clear portions completely surrounded by alteration. Microscopic results place the rock as a somewhat gneissic microcline granite.
Post Carboniferous.

The moderately coarse gray granite that intrudes the limestone of Queen hill is placed as the earlier of the post-Carboniferous intrusives. Only one exposure of what is thought to be the same granite has been mapped. This outcrop is along the wash just north of the Butte shaft. Even in this one case there is altered granite about a quartzite block which in thin section is somewhat like the pre-Carboniferous. Both weathered and fresh specimens are quite similar in appearance to the granite mapped as pre-Carboniferous. In the hand specimen fresh surfaces are dark gray with the feldspar standing out in quartz crystals of smaller size. Dark patches occur throughout the rock and are evidently the alteration product of some ferro-magnesium mineral. Some epidote was noted and stringers of pyrite occur near the contact. Another area which may in part be classed with this earlier intrusive occurs along the wash east of the southwest projection of the district. There is evidence of intrusion in this region and in both the main washes that extend to the west. That in the washes appears to have been dikes but in the main granite area the evidence is not so clear.

Thin sections of this earlier post-Carboniferous rock show orthoclase, oligoclase and quartz as the principal primary mineral. The quartz is present in lesser amount than the other two. Nothing but what might be altered remnants were found to indicate a ferro-magnesium
Fig. 8. Earlier post Carboniferous Granite showing oligoclase, quartz and orthoclase with secondary quartz and chlorite.

Fig. 9. Granite similar to 8 only near contact showing development of diopside and chlorite.
Perhaps the main cause for this condition was the necessity of taking specimens near the contact with the limestone. Some microperthite was noted. Magnetite and apatite are accessory. Quartz and chlorite have come in as secondary minerals, the former as small interlocking crystals surrounding the larger primary crystals. Some of the chlorite is perhaps the result of alteration of a former ferro-magnesium as is true of some iron oxide. Among the alteration products are sericite, kaolin and paragonite. From the information secured this rock is classed a granite with monzonitic aspects. Its age may be early Mesozoic which age has been assigned to similar granites at the Dome Rock Mts.*, in western Maricopa County **, and in the Santa Rita Mts.*** where Schrader has mapped it with the pre-Cambrian because it could not be differentiated due to similarity in composition and appearance of the two rocks.

The later post-Carboniferous intrusive is exposed on the southwest of Morgan Hill forming an intrusive contact with the post-Carboniferous quartzite. Near the contact it is altered to a light brown color with numerous

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plates of biotite grading into a dark gray biotitic rock away from the hill. Outside the area mapped it is found less than a mile to the northeast where it intrudes the limestone (probably Carboniferous) of the Twin Buttes. The placing of this intrusive as later than the granite at Queen hill is rather arbitrary the chief evidence being that it intrudes younger rocks and its lithologic character is more like other intrusives placed as late Mesozoic in age. Other possibilities are magmatic differentiation and simultaneous intrusion.

Thin sections show orthoclase, plagioclase, quartz, biotite and hornblende as the main primary minerals. There are two generations of quartz, that coming later being the more abundant. Zonal structure is prominent on the plagioclase the majority of the crystals being so affected. Extinction seems to indicate gradation from acid andesine to oligoclase. Biotite which is very prominent in the hand specimen does not seem to be so widespread in the sections. Hornblende is present in almost equal amount. Most portions of the rock show considerable alteration especially near the borders. This rock should perhaps be classed as a granodiorite.

Dikes.

The most prominent dikes are the large white aplitic granite ones which intrude the pre-Carboniferous. No definite evidence of their intrusion into any of the sediments was noted. Still this is not absolute proof of their earlier
age since it is often the rule to find acidic dikes of this kind wholly contained in the granite which has produced them. In thin section this rock shows microcline, plagioclase, apatite and evidence of other minerals too altered to distinguish. These dikes have a general NE-SW trend and are found only in the pre-Carboniferous granitic area.

Apparently coming off from the granite southwest of the Senator Morgan hill is another set of dikes that intrude both the Carboniferous and post-Carboniferous rocks. Near the extremities furthest from the granodiorite these dikes are made up chiefly of feldspar and quartz. Both orthoclase and plagioclase feldspar are usually represented and in one case microcline was noted. As a rule these dikes are quite coarsely crystalline and somewhat pegmatitic in character. Nearer the granodiorite where they widen out accessories and some ferro-magnesium minerals were noted. A dike of similar composition and somewhat gneissic was found in the shallow ravine northeast of the Senator Morgan shaft and there is evidence of similar conditions in the main wash further north.

Just north of the Senator Morgan garnet zone evidence of a porphyry dike was found. Another similar dike was found at the southwest base of Minnie hill, this latter showing evidence of mineralization. Sections of both these dikes showed cryptocrystalline quartz with occasional altered phenocrysts some of which showed albite twinning.

In the area east of the southwest projection
where as previously mentioned there is probable evidence of intrusion part of the rock mapped as pre-Carboniferous appears finer grained and dioritic. This same condition was noted in several other localities but was taken in most cases as a variation within the one granite.

Perhaps some mention should be made of quartz veins all apparently composed of barren bull quartz. They are most prominent just southwest of the old Senator Morgan shaft where several of them have been mapped. In general they seem to be closely connected with the garnet areas. Some of these garnet rock contain vugs lined with quartz crystals.

STRUCTURE AND METAMORPHISM.

Folding and Faulting.

The eastern sedimentary area shows no evidence of folding and in the western group although relations are not so clear, there is little to indicate any major folding. Some of the limestone, especially that in the west has some large gradual flexures and a number of smaller crenulations. But on the average aside from tilting and faulting the beds have been unchanged.

Faulting has been the dominant result of the dynamic forces that have affected the region. Those in the eastern sedimentary group trend NE-SW and the majority are of small displacement. Three stand out prominently among them, however, namely the one cutting diagonally through El Pie hill,
the one at its northwest base and the fault cutting through Minnie hill. The displacements along these faults are approximately 400, 300, and 200 feet, respectively. To the east of the diagonal fault on El Pie hill the beds strike northwest and dip to the northeast while on the west the strike is approximately the same but the dip is to the southwest. These conditions suggest that the fault is of the hinge type. The western sedimentary area appears to be still more faulted than that to the east and because of poorer exposures and greater shattering they are much more difficult to trace. Only where there may be some relation to the ore deposits or where definite displacements of considerable size have been noted has there been any attempt to map these faults. As in the east, the principal direction of faulting appears to be NE-SW. The throw on most of them is evidently less than on the larger ones mentioned above for in no place is there such large displacement. Evidence of widespread faulting and shattering is seen in drifts from the 400 station at the Gladstone shaft. Blocks of various types of limestone and quartzite are cut in rapid succession.

### Intrusion

Besides being the ultimate cause of faulting intrusion has resulted in widespread metamorphism. Practically all the limestone in the district has been recrystallized giving various stages of marblization. Metamorphic minerals have been produced among which garnet in the lime-
stone is the most prominent. These garnets probably near andradite in composition occur in large number in portions of the limestone, especially near the contact and above the ore bodies. They form dark gossan-like areas and have considerable magnetite associated with them. In addition chlorite, actinolite and hedenbergite have been produced in the limestone near the contact. Actinolite in bands of numerous small fibres was found at considerable distance from the contact. Chlorite and diopside were noted in the granite near the contact at the Queen Mine. The more shaly limestone at the Minnie Mine has been silicified in part. Shale east of the Senator Morgan Mine has been converted to hornfels, while the quartzite of the hill to the south has had epidote up to nearly half the rock developed in it. It was probably a calcareous sandstone originally.

ORE DEPOSITS.

Types of Deposits.

The ore deposits of the Twin Buttes District are contact metasomatic deposits in limestone of Carboniferous and pre-Carboniferous age at or not far from igneous intrusives. They are chiefly copper bearing with chalcopyrite the main copper mineral. The deposits are similar to others found in Arizona at Silverbell, Washington Camp, Apache Camp, Christmas and in part to portions of the deposits at Bisbee and Morenci. Those deposits in the Twin
Buttes district not definitely associated with igneous intrusion (although never far distant) are grouped as contact metasomatic using as the criteria for classification the type of primary mineralization. In general the ore bodies occur about the periphery of the limestone areas close to its contact with igneous or other sedimentary rocks. Two of the ore occurrences, namely the upper portions of the Old Senator Morgan and the mineralization at the North Star somewhat resemble high temperature vein deposits. However, if such is the case they have been superimposed upon a former contact mineralization.

Mineralogy.

The primary minerals noted in the various deposits include chalcopyrite occurring in the massive contact bodies intimately intergrown with the other metallic minerals and gangue, in varying proportions. In the secondarily enriched portions it occurs as residual masses in chalcocite. Pyrite is the most widespread and probably present in the largest quantity of any of the metallic minerals. It occurs as euhedral grains in or as masses cut by chalcopyrite. Pyrrhotite occurs in minor amount and also appears as grains in the chalcopyrite. Sphalerite is present in very minor amount and except at the North Star Mine there is no evidence that it ever was of importance in any of the ores. Galena occurred in the upper portions of the old Senator Morgan formerly outcropping along the north of the
old shaft. Some probably occurred with the zinc at the North Star. Marcasite either primary or secondary (probably as a late primary replacement) occurs mainly as a replacement or alteration product of pyrrhotite. Magnetite was noted in varying amounts being especially prominent at the Senator Morgan Mine. The same is true of specularite. Among the gangue minerals garnet (andradite) diopside, actinolite, hedenbergite, epidote, chlorite, vesuvianite (?) and quartz were noted. Among these andradite, chlorite, actinolite and probably epidote are the most prominent.

Of the secondary minerals chalcopyrite is the most prominent. In the enriched portions of the Queen and Glance ore bodies it occurs as masses practically pure. Native copper occurs as small particles developing in chalcocite ore and as wire copper with various oxides. Copper pitch occurs as an intermediate step in the development of native copper from chalcocite. Malachite and chrysocolla were noted in the upper oxidized parts of the ore.

**Hypogene Mineralization.**

The ore forming solutions (liquid, gaseous or both) apparently were given off soon after the magma or magmas intruded the sediments. That they continued to be given off for a considerable time is evidenced by the veinlets of ore in the borders of the intrusive itself. Polished sections seem to show an intimate intergrowth of ore and gangue in most cases indicating nearly simultaneous growth.
To account for the repeated occurrence of the sulphides in garnet or with garnet as one wall is more difficult. Broad relations seem to indicate a concentration of metallic solutions at certain favorable places leaving the silicate solutions the rest of the rock with of course a certain amount of intermingling. So that we find massive ore with a low percentage of silicates in pockets completely surrounded by silicate rock (especially garnet) with little ore. Where the intrusives are revealed there seems to be a decided tendency for the ore to make on the limestone side of the garnet rock and yet remain within the garnetized area. Umpleby* has advanced two theories for this phenomenon and favors a change in composition of the solutions from the magma. However, considering the evident intergrowth of the ore and gangue minerals precipitation of the ore minerals at a lower temperature seems logical to account for their occurrence on the periphery of the mineralized zone. So as between ore and gangue there seems to be little to indicate separate periods of deposition. Among the gangue minerals themselves the garnet appears to be the earliest, with chlorite and quartz, probably the last to form. For the sulphides the relations are more clear and a fairly definite order of formation indicated. It is as follows: pyrite, pyrrhotite and magnetite, chalcopyrite and sphalerite, marcasite. In this particular ore galena was not

noted. Evidences for this order will be more fully discussed under ore deposition at the Queen, realizing that such deductions are always open to error from misinterpretation of the true relations of minerals in contact with each other on polished surfaces.

**Oxidation and Supergene Enrichment.**

Contact metamorphic deposits commonly show but little secondary enrichment and at Twin Buttes the main production has been from unenriched sulphides. This is probably due to the comparatively impermeable character of contact deposits resulting from the massive development of hard tough silicates and ore. Ineffectiveness of enriching processes upon this type of deposit is well illustrated at the Senator Morgan where workable ore was found at the surface. However, portions of the Queen and Glance ore bodies have been thoroughly affected by oxidation and enrichment which have formed considerable high grade supergene ore. In general the stages in the development of the enriched ore seems to have been oxidation of the original sulphide bodies. Removal of most of the copper to depth forming enriched chalocite ore bodies largely where the former sulphide ores occurred. Development of native copper also has taken place near the top of the chalocite, with the contemporaneous formation of copper pitch and various copper oxides. The conditions which have affected this type of enrichment
are summarized by Emmons* as follows: Conversion of pyrite to ferrous sulphate and sulphuric acid by oxidation and hydration and in turn the development of ferric sulphate which is an active solvent of the copper sulphide carrying them down perhaps in stages in the form of sulphates. Upon reaching reducing conditions there is a reaction of these solutions with the original sulphides producing secondary Cu2S. This latter may be changed to native copper and oxides of copper by a downward migration of oxidizing conditions. Some of the oxides often result from reaction with the wall rock where it contains sufficient calcite.

MINES.

Senator Morgan.

The Senator Morgan ore body is near the contact of the Carboniferous limestone and the post-Carboniferous shale. It seems to be localized by intersecting fault zones and is associated with an intrusive porphyry dike. Only portions of the upper two levels are now accessible due to water and caving. The top level is 125' from the collar of the new Senator Morgan shaft. In the first crosscut to the N there is exposed 23 feet of limestone, 22 feet of porphyry, 8 feet of limestone, 5 feet of garnet and 65 feet of siliceous limestone. The beds strike N 35° W and dip 55° to the SW. The main drift of the first level runs 720' to

the old Senator Morgan shaft, the first one-third going N 40° W, the next N 70° W and the last S 30° ... 340' from the new shaft the drift opens into a stope 60' high which in relation to the surface would be 35 feet to the east of the tunnel and SW fault shown on the map. The long axis of this stope is N 86° W and the dip is 47° to the SW. The footwall is of soft limestone and gouge with a band of garnet just to the south and then ore in the limestone adjacent. A cross cut from the stope, to the south encounters limestone rich in iron some of the beds being practically all magnetite, then calcareous shale and toward the end siliceous shale. This stope is connected by raises with others below down to the next level. These lower ore bodies are in garnet, between garnet and the limestone and between the magnetitic limestone and the limestone. They have the same general dip and relation to the foot gouge as the stope above. The foot wall gouge seems to be the result of the E-W fault shown at the surface, while the local concentration at this point suggests that the N-S fault dips to the E and cuts the main fault at this location underground.

The ores removed were largely primary copper sulphides with some galena and high in magnetite and specularite. At the surface there were local concentrations of partially oxidized copper ores. Sulphide ores of copper occurred from near the surface to a depth of 355 feet where they are said to grade into ore of too low tenor to mine. The occurrence of galena at the surface just north of the
original Senator Morgan shaft and in upper portions of the mine suggest a rude zoning with the base of a high temperature vein superimposed upon the top of the contact deposits. Specimens collected by C.H. Clapp fourteen years ago show garnet rock with considerable galena associated.

**North Star.**

The North Star Mine is in garnetized Carboniferous limestone at the contact with the supposed pre-Carboniferous granite. There are two levels, one at 150 feet, the other at 210. Crosscuts from the shaft to the south and west reveal a band of garnet with some ore and a crystalline limestone to the west all apparently striking a little west of north and dipping southwest. The ore is made up chiefly of oxidized lead and zinc minerals, chiefly the latter. None has been shipped.

**Minnie.**

The Minnie ore body is in pre-Carboniferous limestone near to granite on the north. There are levels every 50 feet from a depth of 50 to 250 feet. The ore seems to be bounded on the west and northwest by a fault which has brought the pre-Carboniferous quartzite in contact with the limestone. This fault flattens and swings northeast with depth so that at the 250 foot level the mine bottoms in quartzite. Each level shows a continued encroachment of the quartzite from west to east which indicates that the fault dips in the
latter direction. Some oxidized ore was found near the surface and at 50 feet primary sulphide copper ore chiefly chalcopyrite was encountered and continued down to the quartzite. Where the limestone was more shaly certain beds show replacement by ore while others were silicified.

Glance and Queen.

The Glance and Queen ore bodies are very similar in character and location. They are in Carboniferous limestone at the contact with an intrusive granite. The main difference between them is the more broken character of the rock at the Glance and therefore a greater amount of oxidation and enrichment. Most of the drifts and crosscuts required timbering and are now inaccessible due to caving. The ore was similar to that being mined at the Queen with which it is connected by a tunnel on the 600 level.

The Queen ore body is at present the only productive one in the district and because of its accessibility it was studied more in detail than the others. Geologic plan maps (plates 6 to 11) show the distribution of granite, garnet, limestone, and ore on the different levels. These show the tendency of the ore to make in the garnet zones and in general to the limestone side. No productive ore bodies with the exception of some oxidized ore were encountered until the 440 level was reached. Here a band of garnet along the granite footwall yielded some oxidized ore while an irregular mass of garnet separated from it by
crystalline limestone yielded a good sized stope of enriched ore. Little ore was found on the 500 level, the enriched ore stope above pinching out and small top of another enriched ore body below being the only ore encountered. On the 540 the top of a sulphide stope was cut to the west of the station, while on the east there was a large body of enriched ore with some native copper between the two levels. A series of large sulphide ore bodies of irregular shape open out from the station at the 600 level extending a short way to the southeast and a considerable distance to the northwest. The enriched ore area on the east begins to grade into sulphide ore below. Similar conditions prevail on the 650 level with an increase in sulphide ore partially enriched at the east end. The 700 level marks the bottom of the ore on the east end and practically complete pinching out of all the bodies of the west end with the exception of the large central stope which appears to extend somewhat below the 700. Diamond drilling at the end of the drift southeast from the station revealed granite at depth not much over 100 feet showing that the contact flattens to the south. No ore was encountered. The development of enriched ore exclusively in the east end of the mine seems to be due to the more crushed condition of the rock in that locality, especially near the contact. This crushing may be due to the intrusion of the granite between Queen and Glance hills which, because
it is across the bedding would produce more shattering than that along the axis of the hill which is parallel to the bedding. Again the ore bodies are nearer the contact in this part of the mine also indicating the effects of the shattered zone as a channel for solutions. The garnet crec are in a general way parallel to the bedding as revealed at the surface but their association and curving with the contact suggest that this is in part due to the approximate parallelism between the contact and the beds. In some cases garnet zones seem to make out along fissures a notable case, being revealed at the surface along the King tunnel. Faulting seems to be mainly post mineral and of small throw.

A study of polished specimens of ore from different portions of the mine show the primary sulphide ore to be made up of chalcopyrite and pyrite in varying proportions as the chief constituents. Other minerals include magnetite, pyrrhotite, sphalerite and marcasite. The typical occurrence is euhedral crystals of pyrite with mixed pyrrhotite and magnetite about its borders and all apparently engulfed by chalcopyrite with some sphalerite associated. Marcasite occurs in concentric rings about the pyrrhotite and in association with quartz veinlets often where no pyrrhotite is revealed. These relations were used in determining the paragenetic order previously advanced.

The occurrence and structure of marcasite are difficult to explain. Under high power considerable of
Fig. 10. Unaltered and unenriched ore. prr - Pyrrhotite, mg - Magnetite, cp - Chalcopyrite, g - Gangue.

Fig. 11. Two modes of occurrence of Marcasite. A. - Coming in along a quartz vein no Pyrrhotite noted. B - replacement of Pyrrhotite by Marcasite. prr - Pyrrhotite, m - Marcasite, cp - Chalcopyrite, q - quartz, g - gangue.
Fig. 12. Pyrrhotite nearly completely replaced by Marcasite. prr - Pyrrhotite, m - Marcasite, g - gangue.

Fig. 13. First stage of enrichment showing chalcocite coming in along quartz and mineral boundaries. cc - Chalcocite, cp - Chalcopyrite, py - Pyrite, q - Quartz
the concentric structure appears to be due to quartz or other minerals in the concentric cracks cutting it. Darker concentric bands of pyrrhotite were also noted and seem to add to the general effect. Its prevalent occurrence in association with quartz and as an alteration or replacement of pyrrhotite in apparently fresh massive sulphide ore suggest that it may be a late lower temperature primary mineral. Boydell* states that the concentric structure of marcasite is probably due to colloidal deposition while P.A. Wagner** is of the opinion that alteration is the cause. The occurrence of silica and other minerals in the concentric cracks would seem to support the theory of colloidal deposition. Where marcasite is found along quartz veins without any sign of pyrrhotite and where it occurs mixed with magnetite and quartz as small concentric layered grains as in a specimen collected from the dump last year by Mr. Webber its true relations and mode of deposition are difficult to determine. But when compared to specimens from the mine which show all stages from small pyrrhotite grains completely replaced to large grains with just a trace of marcasite about the borders it seems conclusive that the main locus of its development is at the expense of pyrrhotite.

*Boydell, H.C., A Discussion on Metasomatism, Econ. Geol., vol. 21, pp. 1-55.

Fig. 14. Enrichment further developed leaving blocks of chalcopyrite engulfed in chalcocite that has come in along Quartz veinlets. cc - Chalcocite, cp - Chalcopyrite q - Quartz.

Fig. 15. Last stage of enrichment showing the development of native copper from chalcocite with copper pitch as an intermediate stage. cu - Native copper, ml - Melanomite, cc - Chalcocite.
The development of enriched supergene ore bodies as revealed by polished specimens show that chalco-
cite brought down by solutions from above penetrates the original sulphide ore along minute quartz veinlets. It re-
places the chalcopyrite along these veinlets gradually spreading out until the chalcopyrite occurs as blocks or "floating ice cakes" in the chalcocite. Where pyrite occurs the chalcopyrite is attacked in preference to it giving chalcocite stringers through the pyrite where the "ex-
ploding tomb" structure previously existed. Finally the process reaches the stage where the ore is all massive chalcocite after which it may be subject to oxidizing con-
ditions which will result in native copper and copper oxides.

SUMMARY.

Future of the District.

The Copper Queen which is the last pro-
ductive mine left in the district appears to be nearly work-
ed out. The ore in sight apparently will not maintain pro-
duction at its present rate longer than the end of the year. Diamond drilling from the 700 level has not revealed any ore at greater depth. This leaves but one place to prospect in the immediate locality, namely to the west between the Putte shaft and the Queen. Two years ago when conditions were much the same as now drifting to the east revealed the enriched bodies below the leached areas of the levels above
and gave the mine a new lease of life. So although there are no surface indications of ore, some might be found by following the contact into this unprospected ground. On the other hand the notable irregularity of contact deposits may have resulted in leaving this buried portion of the contact barren. The present operators are placing most of their hope in the new Gladstone prospect which seems to be the most likely in the district. To date nothing encouraging has been encountered in the drifts from the 400 station.

Conclusions.

The ore deposits at Twin Buttes are clearly contact metasomatic with the development of such characteristic minerals as magnetite, pyrrhotite, chalcopyrite, hedenbergite, andradite, diopside, epidote and actinolite. They were formed in limestone at or near the contact of an intrusive igneous rock which furnished the solutions that caused the mineralization. This mineralization formed such compact deposits that except in cases of later shattering little enrichment took place. Marcasite which is the most unusual mineral in the deposit appears to be a late primary mineral deposited at the expense of pyrrhotite. The occurrence of the garnet zones and the ore itself at certain localities along the contact is due in large part to the natural vagaries of contact action, and likely to favorable beds and fissures in other cases. The occurrence
of the ore in the garnet zone nearer the limestone than the granite contact may be due to precipitation of the metallic minerals at a somewhat lower temperature than most of the garnet. The shallow depth at which the deposits bottom in the Queen Mine is in accord with the observed fact that where contacts flatten out they are not conducive to ore deposits.
LONGITUDINAL SECTION
N.54°W THROUGH THE QUEEN SHAFT
MAY, 1926
RONALD BROWN
Scale 1"=20'

Plt e V.