GEOLOGY AND ORE DEPOSITS OF THE REBEL MINE AREA
BEAVER COUNTY, UTAH

By

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ABSTRACT

The Rebel mine area includes about one-quarter of a square mile in central Beaver County, Utah. It lies in the northeastern end of the Star Range, in the Star (or North Star) mining district, five miles west of the town of Milford.

Exposed sedimentary rocks consist of about 2000 feet of limestones, sandstones, and siltstones. The following units, named by Townsend (1953), were recognized: Rebel limestone, "unnamed" quartzite, and Williams limestone, from bottom to top. The Rebel unit consists of 1200 feet of recrystallized and bleached limestone. The "unnamed" quartzite is a silicified quartz sandstone which ranges in thickness from 160 to 550 feet. The Williams unit consists of at least 500 feet of limestone, very similar to the limestone of the Rebel unit.

Along the western edge of the study area is a sequence of limestones, quartzites, and shales which is unrelated to the strata found in the rest of the area. This sequence appears to be separated from the Rebel limestone-Williams limestone sequence by a low-angle fault.

Intrusive rocks of quartz-monzonite porphyry are present in the Rebel mine area as phacoliths, sills, dikes, a stock, and smaller apophyses. A little aplite and some dark inclusions of monzonitic composition were found in the porphyry. From field relationships, the following conclusions are drawn:

(1) The intrusions were implaced at a relatively shallow depth. (2) The intrusions formed during or after folding and were intruded along zones of weakness formed by tensional stress at or near the crest of the major fold. (3) The surface rocks are probably underlain by a large "parent" intrusion. (4) The age of intrusion is probably Cretaceous but may be Tertiary.

The features of contact metamorphism observed are (1) recrystallized and bleached limestones, (2) silicified sandstones, (3) skarns, (4) hornfels, and (5) veinlets of calc-silicate minerals, calcite, and quartz in the porphyry. The metamorphism proceeded as follows:

1) Large amounts of barren fluids exuded from the magma caused widespread recrystallization and bleaching of the limestones.

2) After solidification of at least the outer parts of the intrusions, a second, more limited, stage of fluids was exuded from the magma at depth. These cation-rich fluids rose through the permeable sandstone and siltstone beds, along tension fractures in the limestone, and along the limestone-porphyry contact, forming hornfels and skarns.

3) A third stage of fluids deposited malachite in cracks in the skarn minerals. However, these fluids were possibly not magmatic.

Two basic types of skarns are recognized, barren and ore-bearing The barren skarns are composed of calc-silicate minerals only. The ore-bearing skarns have in addition the following ore minerals: specular hematite, magnetite, malachite, azurite, chalcopyrite, and scheelite.

Folds, faults, and fissures are important in the Rebel mine area. The principal fold is a tight anticline which plunges about 65 degrees to the north. This fold localized the intrusions. Two NW-striking faults are cut by the N70E-striking Rebel fissure. It appears to be one of a large number of similar fissures which are found in the Harrington-Hickory mine area and the White Rock mine area. The larger of the two faults in the Rebel area is apparently the same fault which Townsend (1953) mapped as the East Fault in the Harrington-Hickory mine.

At least 41 minerals, including the uncommon species ludwigite, clinohumite(?), and allanite, are present in the study area.

Ore deposits are of both the contact metamorphic type and the fissure-filling type. The Rebel mine develops the fissure ore deposit. It was an important lead-silver producer in the 1870's. The ore consists of argentiferous galena and cerussite along with lesser amounts of iron, manganese, zinc, and copper minerals.

Three factors appear to have controlled the deposition of ore: the fissure, intersections of the fissure with pre-mineral faults, and limestone country rock.

The potential of the Rebel mine as a future producer seems good. A systematic underground exploration program should be undertaken.

An analysis of the Rebel dumps indicates a metal value of roughly 119,000 dollars in about 3500 tons. At this time the dump material is not ore.

INTRODUCTION

PURPOSE AND SCOPE

The purpose of this study is to investigate the geology and economic potential of the area immediately around the Rebel mine (herein called the Rebel mine area, Rebel area, or study area). Primary attention is given to the ore deposits of the Rebel mine and to aspects of the geology which may lead to an understanding of the Rebel ore bodies in the study area. The geologic structure, igneous rocks, contact metamorphism, and mineralogy are given especial emphasis. An analysis of the potentially valuable Rebel mine dumps is included as an appendix.

ACKNOWLEDGEMENTS

This paper has benefited greatly from the contributions of a number of interested people and organizations. The writer especially wishes to thank Dr. James A. Whelan for his advice, encouragement, and direction. The Utah Geological Survey, under the direction of Dr. Wm P. Hewitt, provided the funds for field expenses, thin sections, and assays. Dr. Don Mayer, Milford, Utah, was kind enough to fly the writer over the Rebel area so that oblique aerial photographs (fig. 2) could be taken. A number of graduate and undergraduate students provided helpful criticisms and advice, for which I am especially grateful to Messrs. Arthur S. Gallenson, S. Kerry Grant, Robert B. Kayser, M. Leroy Sutton, and Kenneth C. Thomson. Dr. Whelan, Mr. Grant, and Mr. Kayser critically read the manuscript and offered many valuable suggestions for its improvement.

LOCATION AND GENERAL ECONOMIC FACTORS

The area investigated is located in the northeastern part of the Star Range, in the Star (or North Star) mining district, approximately fives miles due west of the town of Milford, Beaver County, Utah (see index map, fig. 1). The area mapped is about one-quarter of a square mile and is 3000 by 4000 feet in maximum dimensions. Most of the area is shown in figure 2. The area straddles the common corner of sections 4, 5, 8, and 9, T28S, R11W (SLB&M).

Milford has a population of about 1400 people. It is a major division point on the Union Pacific Railroad line from Los Angeles to Salt Lake City. Milford is essentially a railroad town, although the town also serves cattle ranches and hay farms, and provides the supplies and point of shipment for such mines as are still operating in western and central Beaver County. Tourist trade is nil. However, the town is supplied with a normal contingent of stores, gas stations, cafes, as well as two hotels, a motel, and a bank. Sufficient labor for a small mining operation can easily be recruited from the area.

The Rebel mine is admirably situated with regard to mining operations. An improved, all-weather dirt road extends from the Harrington-Hickory mine, located 600 yards south of the Rebel workings, directly to loading ramps on the Union Pacific Railroad. Several dirt roads connect the Rebel workings with the improved Harrington-Hickory access road, and any one of these Rebel access roads can easily be made suitable for regular ore shipment. The Rebel workings are located on the edge of the Escalante Valley, and the drop in elevation from the mine adit to the loading ramps on the railroad is only 530 feet. The Tooele custom smelter,

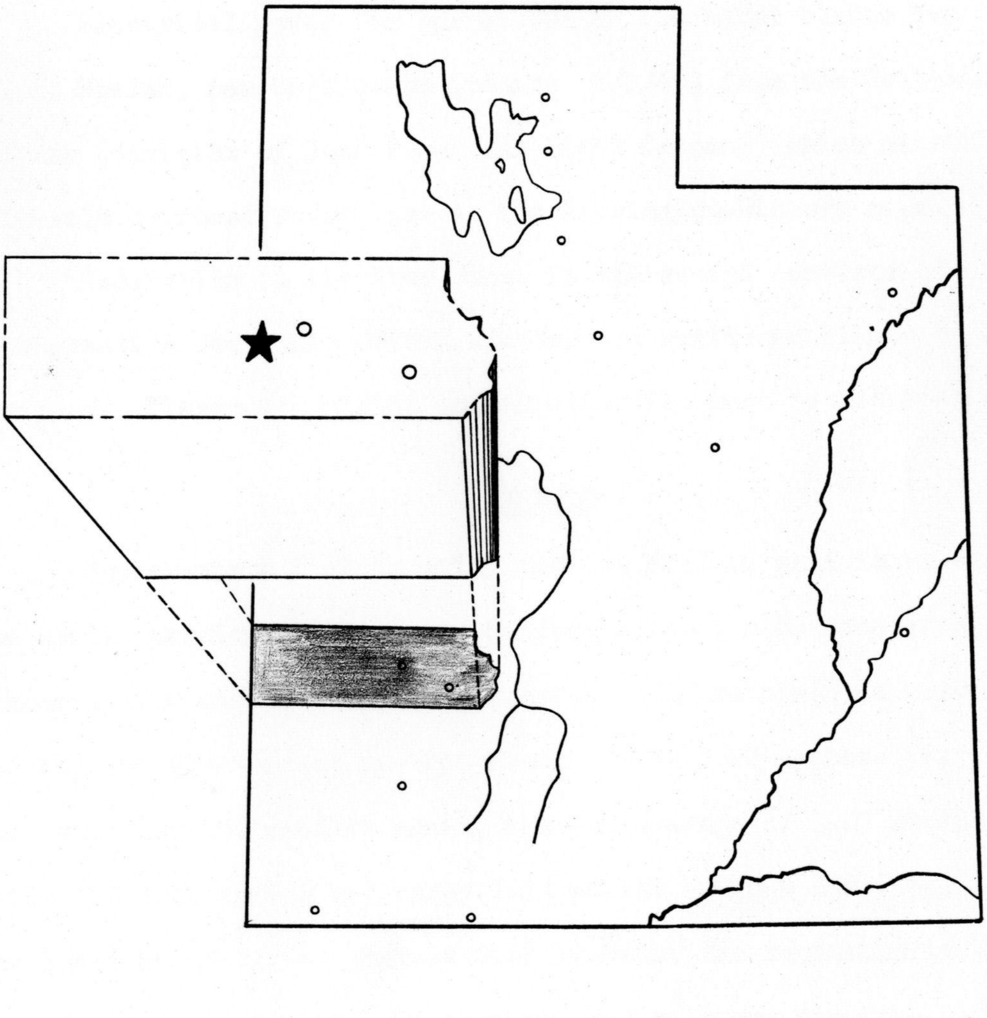

Fig. 1.- Index map of Utah showing the location of the Star Range.

operated by the International Smelting and Refining Company, is approximately 215 miles by railroad north of Milford.

Water is a scarce and valuable commodity in the area around Milford. Most of the water for the area is derived from shallow wells in the valley near the town. However, in the Star Range the water table is at great depth. At the Harrington-Hickory mine just south of the Rebel, the water table in 1953 was slightly below the 500 foot level (Townsend, 1953).

Electrical power for operations on the Rebel claims can be obtained (J. A. Whelan, personal communication, 6/3/65) from the Telluride Power Company (division of Utah Power and Light Company) which maintains a 5000-volt overhead power line to the Harrington-Hickory mine.

Vegetation in the Star Range is sparse and consists of sagebrush, bunchgrass, a few spiny desert plants, and scattered clumps of twisted junipers. Timber for mining and construction must be obtained elsewhere.

CLIMATE

Southwestern Utah is arid, and the Milford area is no exception. The annual precipitation at the Milford Airport U.S. weather station averages 8.00 inches per year. However, this rainfall is capricious, and any one given month may get from 0.00 to 3.00 inches. March is statistically the wettest month, with an average of 1.03 inches moisture, while the late spring and early fall months of June and September receive the least rainfall, an average 0.43 inches. The mountains in the Basin and Range province generally receive more moisture than the valleys, so the Rebel mine area probably receives somewhat more than eight inches of moisture per year.

The yearly temperature variation in the area is not excessive and the summer and winter months are quite bearable. Temperatures at the airport range from an average of 24.6° F in January to 73.8° F in July, the hottest month of the year. The yearly average is 48.9° F. The daily temperature range is usually large and may be 30° to 40° F in the summer. Summer highs are as much as 110° F, while winter lows fall to -20° F occasionally.

FIELD WORK

The necessary field work was accomplished in several short periods during the fall and winter of 1964-65. The writer was first introduced to the study area in late October, 1964, by Dr. J. A. Whelan of the University of Utah. The major part of the field work was completed by the author alone in a nine-day period from Thanksgiving Day through December 4, 1964. A final look at the area was obtained during a three-day period from January 31, through February 2, 1965. The writer was accompanied by Dr. Whelan and Mr. George Horman of the Shell Oil Company, both of whom were in the Star Range to examine other problems as well as the problems in the Rebel mine area. The writer and Dr. Whelan spent part of one day examining some of the underground workings in the study area.

The surface geology of the study area was plotted on an aerial photograph enlarged to an approximate scale of 1 inch = 400 feet. Due to distortion, the actual scale on the photograph ranged from about 1 inch = 365 feet to 1 inch = 395 feet. The final map was prepared to a corrected scale of 1 inch = 400 feet.

Maps of the Rebel mine and the prospects were prepared in several scales by several people, including the writer. Underground mapping by the writer was done on a scale of 1 inch = 40 feet. Several maps, including the maps of the Rebel adit and surface workings, were prepared by Dr. Whelan and Mr. G. B. Baetcke during the summer of 1964 to a scale of 1 inch = 60 feet. These maps were enlarged by the writer to a scale of 1 inch = 40 feet for this paper.

The writer regrets that the study area had to be so small and its boundaries so arbitrarily defined. The limited amount of available time for field work made it impossible to investigate personally the general geologic conditions in the Star Range. The lack of detailed published geologic work available on the Star Range made it impossible to explain or interpret certain observed features of the geology of the Rebel mine area.

PREVIOUS WORK

Although the mines of the Star district have been worked intermittently since 1870, there has been very little work published on the district as a whole, and no work at all published on the Rebel mine. The first general work of importance was B. S. Butler's U.S. Geol. Surv. Professional Paper 80, Geology and Ore Deposits of the San Francisco and Adjacent Districts, Utah, published in 1913. As an "adjacent district," the Star mining district was not afforded the detailed examination necessary to solve all of the geologic problems in the district. The Rebel mine was allotted one paragraph in this Professional Paper. Prior to Butler's work, the Rebel mine had received scattered attention, chiefly in the local "mining gazettes" and the reports of the U.S. Bureau of Mines. Reference is made to some of these articles in the section dealing with the history of the Rebel workings.

After Butler's paper, the next publications of importance relating to the Rebel mine area are brief U.S. Bureau of Mines reports on the ore deposits of the Vicksburg and Harrington-Hickory mines, by J. W. Townsend (1950 and 1953). They describe only the immediate mine area, and deal chiefly with the results of diamond drill programs.

In the past decade, there has been renewed activity in the Star mining district and surrounding areas. Numerous companies, including Bear Creek Mining and The Anaconda, have conducted extensive investigations in the area west of Milford. Dwight Lemmon of the U.S. Geol. Survey is making a study of four quadrangles, which includes the Star Range (Baer, 1962). James L. Baer (1962) made a reconnaissance study of the entire Star Range for a Brigham Young University Master's thesis. This paper represents a portion of a comprehensive study of the Star Range supported by the Utah Geological and Mineralogical Survey.

GENERAL GEOGRAPHY AND GEOLOGY OF THE STAR RANGE

The Star Range is an irregular group of generally nondescript, low, rounded hills which trend in a north-northeast direction. Its length is about eleven miles, and its maximum width is about five miles near the center of the Range. The hills narrow and gradually merge with the valley alluvium at both ends. The east side of the Range fronts on the broad, flat Escalante Valley, which is drained by the northward flowing Beaver River (intermittent). The west side of the Range slopes irregularly under an overlapping cover of Tertiary volcanics, which have been eroded to gentle hills dissected by an intricate maze of gullies and washes. The volcanic hills are generally covered with juniper and pinyon. The highest peak in the Range is Picacho Peak, with an elevation of 6871 feet above sea level, or almost 1900 feet above the floor of the Escalante Valley. The crest of the range is generally from 6000 to 6800 feet in elevation, except near the ends.

According to Baer (1962), the Star Range consists of 9500 feet of Devonian to Jurassic strata, most of which strike north to northeast and dip to the east at 25 to 75 degrees. The Mesozoic rocks are chiefly sandstones, siltstones, and variegated shales, with some limestone in the lower Triassic Moenkopi Formation. The Mesozoic section is about 3500 feet thick. Paleozoic rocks are mainly carbonates and orthoquartzites. Limestone is the chief carbonate in rocks of Permian and Pennsylvanian age, while dolomite is dominant in rocks of Mississippian and Devonian age. The total thickness of Paleozoic rocks is about 6000 feet. For further details the reader is referred to Baer (1962).

From the works of Baer (1962) and Butler (1913), at least three sets of steeply-dipping faults are present in the Star Range, along with at least two related thrust faults. Thrusting, probably from the southwest, accompanied folding in Cretaceous time (Baer, 1962, p47). Normal faults, striking generally north-south, were developed after the thrust faults. Cutting the north-south faults are east-west faults which are probably strike-slip. Another north-south set of faults cuts the Tertiary volcanic rocks and was probably responsible for elevating the range in relatively recent time.

Granties, quartz monzonites, and granodiorites were intruded in Tertiary(?) time, apparently in part at least along the older north-south fault planes (Baer, 1962, p50). However, the time of intrusion must have been prior to at least some of the east-west faults, for Townsend (1950, fig. 3) shows an intrusion offset by several of these faults.

Most of the ore in the Star district is found in steeply dipping fissures and adjacent bedding replacement bodies (Butler, 1913). These fissures are believed to be post-intrusion features, with the ore solutions presumably derived from the magma at depth.

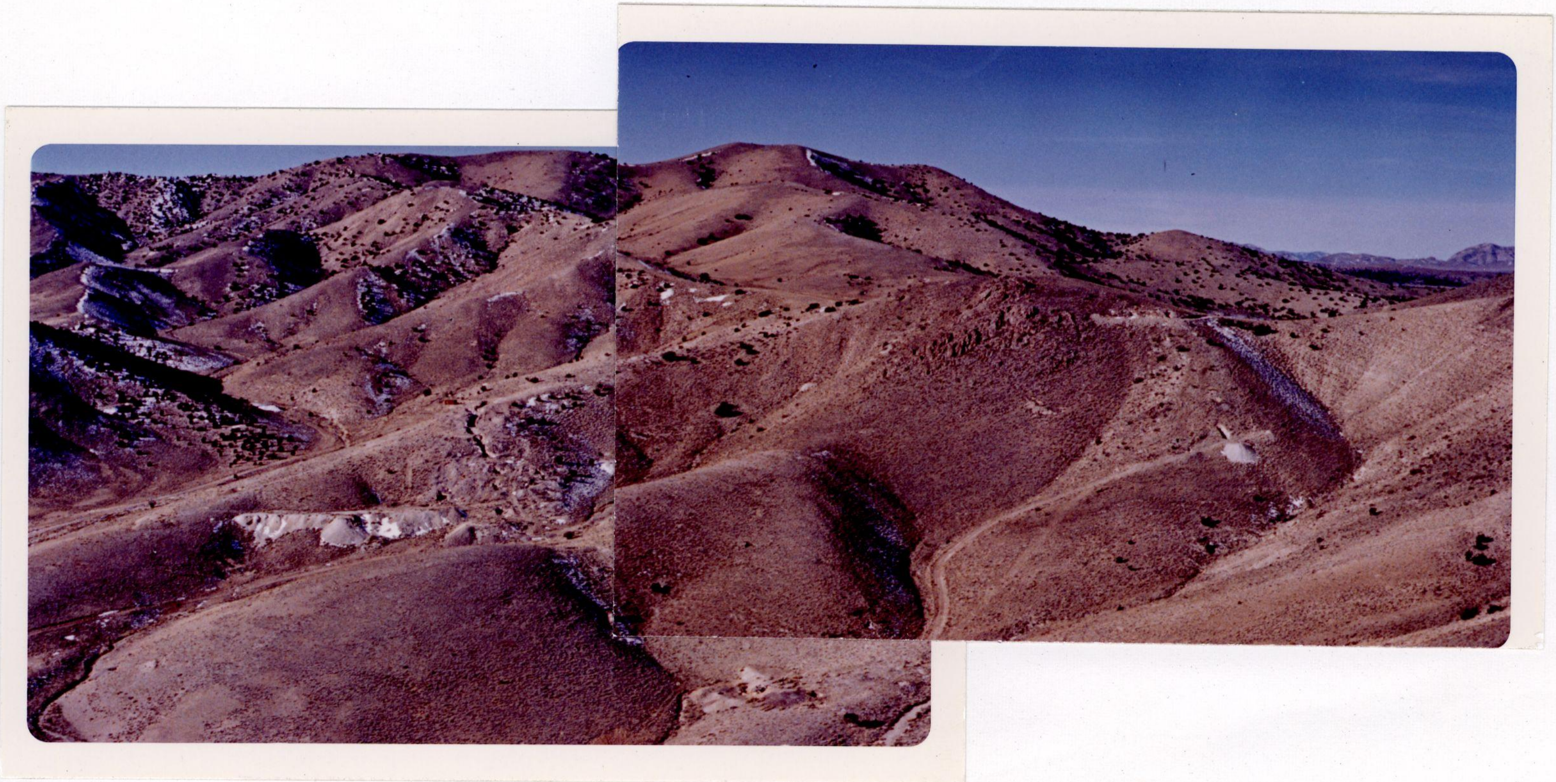

Fig. 2.- Composite photograph of the Rebel mine area from the air, looking west. The San Francisco Mountains are visible in the background.

GEOLOGY OF THE REBEL MINE AREA

SEDIMENTARY ROCKS

GENERAL STATEMENT

The sedimentary sequence exposed in the vicinity of the Rebel mine consists of limestones, sandstones, and siltstones, all of which have been more or less affected by plastic flow during the folding period and heat and fluids during the intrusion period. The total thickness of the section in the area is about 2000 feet, not considering the possibility of repetition and/or omission of strata by faulting.

The exact age of the strata in the Rebel area was not determined. Baer (1962) has mapped most or all of the section in the Rebel mine area as Permian Kiabab, but there seems to be little specific resemblance between his description of the Kaibab and the sedimentary sequence observed in the Rebel area. Butler (1913), who was not primarily concerned with the stratigraphy of the area, grouped on his geologic map (pl. 1) of the northeastern part of the Star Range what Baer now calls Triassic Moenkopi Formation, Permian Kaibab Limestone, and Pennsylvanian Talisman Quartzite into a 5000-foot thick formation, the Triassic Harrington Formation. Mr. George Herman, Shell Oil Company, Farmington, New Mexico, expressed the opinion (personal communication, 2/2/65) that the limestone at (1400S, 50E) on the geologic map (pl. 1), the least altered in the area, looks like limestones of Mississippian age found elsewhere. The writer, in his limited experience, is inclined to agree.

Correlation of the strata was impossible because no macrofossils or microfossils were found. Baer calls the Kaibab "quite fossiliferous" (1962, p38) in macrofossils, although he found no microfossils (p40).

Since correlation was not possible, formational names have not been applied to the rock sequence. Instead, the lithologic unit names proposed by Townsend (1953, p4) for the Harrington-Hickory mine area are used. The sequence, from the bottom to the top, is Rebel limestone, "unnamed" quartzite, and Williams limestone. The units named by Townsend can be directly correlated with the units in the Rebel mine area to the north.

REBEL LIMESTONE

The Rebel limestone occupies the topographically high part of the study area with the exception of the very highest hill, which is quartz monzonite porphyry intruded into the limestone. The limestone is probably around 1200 feet thick, although its true thickness was difficult to determine, due to the effects of folding and plastic flow. The unit forms moderate, rather smooth slopes, as all parts of it seem to have about equal resistance to erosion. Outcrops are reasonably good; soil cover in the higher parts of the study area is absent or very thin.

The unit is mostly limestone and dolomitic limestone which is recrystallized and generally bleached white. A few somewhat-irregular areas in the southern part of the mapped area retain the original dark, bluish-gray color. The limestone is medium-to thick-bedded and is cut by several sets of weak to prominent joints, which make determination of the bedding planes difficult. Where the limestone is bleached white, it is pure and rather featureless. But where the bleaching has not taken place, weathered surfaces on the limestone show irregular resistant veinlets.

A few beds of tan, massive sandstone occur in the lower half of the Rebel limestone (south of the major phacolith). The beds are often cut by cross faults, which is an indication of the rigidity of the sandstone when compared to the limestone. The sandstone is compact, silicified to non-silicified, and non-calcareous. It is composed almost entirely of fine-to very fine-grained (0.3 to $<$ 0.1mm), well-rounded, well-sorted quartz. The fresh surface is usually a light gray to greenish gray. The sandstone weathers to smooth, angular, joint-formed chips. The beds are usually two to ten feet thick, and appear to be lenticular. Several beds in the vicinity of (400S, 500W) (pl. 1) were useful in interpreting the geologic structure.

Several hundred feet stratigraphically above the sandstone beds are several thin beds of light colored hornfels representing argillic and arkosic siltstones and one thicker bed of dark colored hornfels representing argillic siltstone. The beds are separated from each other by variable five-to forty-foot thick beds of limestone (the variation in thickness of the limestone beds is believed the result of plastic flow). The most conspicuous exposure of the siltstone beds is in the general vicinity of (300N, 200W) (pl. 1). Elsewhere, the delineation of the beds was not attempted on the geologic map as the beds could not be traced with confidence in the field. However, three prominent patches of dark-colored rock in the vicinity of (800S, 300W) (pl. 1) are believed to be flow-distorted and broken-up segments of the uppermost, dark-colored argillic siltstone on the basis of general appearance and trace-element analysis (see p). All of the siltstones are now hornfels as a result of contact metamorphism.

The argillic siltstones are composed of from 60 to 90 per cent quartz grains, with the remainder of the rock presumably originally mica, clay, and clay-sized particles. Tourmaline is present as euhedral crystals in amounts ranging from only a trace to a full two per cent. The upper, dark-colored siltstone contains the largest amounts of the tourmaline, which is believed to be a secondary mineral resulting from the introduction of boron during contact metamorphism.

The arkosic siltstone, from one thin section of a specimen taken from near the center of the adit at (250N, 50W), appears to be about 38 per cent quartz and 50 per cent orthoclase, with the remainder originally mostly clays. One per cent tourmaline and three per cent pyrite are also present in the rock.

The contact between the Rebel limestone and "unnamed" quartzite above was not clearly seen, but can be located within several feet and is believed conformable.

"UNNAMED" QUARTZITE

The quartzite which lies stratigraphically above the Rebel limestone forms a belt of varying thickness across the lower part of the study area. It ranges in thickness from 160 feet to probably at least 550 feet. This variation in thickness is believed to be too great to be a result of sedimentary processes only. Possible mechanisms for the apparent variation in thickness are discussed on p . The quartzite, which is uniformly resistant, forms rather smooth, taluscovered hills and ridges which rise above the adjacent limestone beds.

The unit is composed almost entirely of a massive, fine-grained (ave. 0.1-0.2mm) well-rounded, well-sorted, very pure quartz sandstone which has been silicified to a hard quartzite. On fresh surfaces the quartzite is light gray, and on weathered surfaces it is gray to tan gray. There is no trace of the desert varnish which makes the otherwise very similar Talisman Quartzite (found north and west of the study area) a very dark brown on weathered surfaces. The "unnamed" quartzite is strongly fractured or jointed and weathers to irregular, angular chips and blocks. These quartzite chips, seemingly impervious to disintegration, move downhill and almost completely cover the lower-lying Williams limestone. The talus so obscures the limestone outcrops that the contact between the quartzite and the Williams limestone as shown on the geologic map (pl. 1) is very tenuous. It is possible that it is a fault contact.

In the lower 100 feet of the unit are lenticular beds of bleached white, recrystallized limestone which are very similar to the limestone of the underlying unit. In any one place there are usually two to four of these beds, which range in thickness from one foot to twelve feet. These limestone beds could not be correlated with assurance across the valleys.

Also near the base of the unit are irregular thin beds of unsilicified sandstone. The sandstone is usually light tan and friable. It is composed mostly of fine-grained quartz, with scattered grains of magnetite (?) and hematite. The sandstone weathers to rounded blocks and chips.

WILLIAMS LIMESTONE

The Williams limestone forms gentle slopes between the quartzite hills and ridges and the valley alluvium in the southeastern part of the study area. Because the unit is overlapped by recent alluvium, an exact thickness cannot be determined. However, the thickness is at least 500 feet. Townsend (1953, p4) gives a thickness of 600 feet for the unit in the vicinity of the Harrington-Hickory mine. Because of a heavy cover of quartzite float from higher elevations, it was difficult to examine the unit in detail.

The unit is lithologically similar to the Rebel limestone. The limestone is generally bleached white and recrystallized, although there are some beds of dark gray limestone or dolomitic limestone.

RECENT ALLUVIUM

Stream-deposited alluvium occupies the lower parts of the stream valleys and the southern and southeastern part of the study area where the ephemeral streams coalesce.

SEDIMENTARY SEQUENCE WEST OF THE MAJOR INTRUSIONS

A sedimentary sequence completely different from any sequence elsewhere in the study area was recognized on the far west edge of the study area (see geologic map, pl. 1). These rocks are separated from the Rebel limestone-Williams limestone sequence by what appears to be a low angle fault. As the sequence almost certainly has no direct relationship to the ore deposits of the Rebel mine, no detailed work was done on the rocks themselves or on their relationship to the strata in the main part of the area. However, a mention of the rock types, keyed to the geologic map, may be of interest.

A. Limestone, white, generally very fine-grained. The rock is very striking in the field because of a ribbed structure which is deep and pronounced. Dark brown silicified, desert-varnished ribs averaging one-half inch in thickness alternate with pale gray, very fine-grained limestone of equal thickness. Relative relief between the dark and light layers may be one-half inch. The dark layers were probably formed by deposition of silica from meteoric waters percolating into minute bedding plane cracks. Exposure of the resistant silica-rich layers to the atmosphere resulted in desert varnishing by the deposition of iron- and manganese oxides from evaporating surface waters.

B. "Shale," thinly banded, green to white, non-calcareous. The unit forms a steep, smooth slope.

C. Limestone and quartzite. The limestone is white and recrystallized, and in general it is very much like the limestone of the Rebel and Williams units. The quartzite is predominantly purple and white. The purple rock is very noticeable in the field. The quartzite is very fine-grained and appears to be silicified and recrystallized.

D. "Quartzite," green, very fine-grained. The rock may be a silicified or recrystallized impure siltstone or mudstone. The "quartzite" weathers to angular blocks.

E. Float, composed of angular blocks and chips of gray, fine-grained quartzite. This area is flat and is covered by soil. Presumably there is much quartzite directly to the west.

IGNEOUS ROCKS

GENERAL STATEMENT

Igneous rocks in the study area may be classified as phacoliths, sills, dikes, a stock, and miscellaneous smaller apophyses on the basis of structural relations with the country rock. The largest of these bodies is about 900 by 350 feet in maximum lateral dimensions. The intrusive bodies all seem to be of the same mineralogic composition, corresponding to quartz monzonite. However, small dikes of diaschistic aplite are present in the larger phacolith and probably elsewhere. Baer (1962) indicated on his geologic map the presence of two lamprophyre dikes just east of the larger phacolith, but the writer was not able to locate these.

DESCRIPTION OF ROCK TYPES

Quartz Monzonite Porphyry

Two estimated modal analyses of typical specimens from the stock (800S, 800W) (pl. 1) and the larger phacolith (0N, 400W) (pl. 1) are given below.

	Stock	Phacolith
Quartz	6 %	10 %
Orthoclase	40	45
Plagioclase	47 ($An_{ave.}$ 32)	37 (An_{27-36}, ave. 31)
Hornblende	4	5
Biotite	2	2
Magnetite	1	1
Other	<1	<1
	100 %	100 %

Johannsen no. 226"/7"

Virtually all of the porphyry in the area has the same hand-specimen appearance. The rock is mottled white to pinkish gray and weathers to rounded, roughly equidimensional blocks. On fresh surfaces, black lustrous biotite and hornblende crystals are seen scattered between larger euhedral to subhedral crystals of white plagioclase and pinkish-gray orthoclase. The orthoclase phenocrysts are as much as 1.5 cm long, but they do not show any tendency to weather out. The rock appears to be a porphyry.[1]

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[1] A rock "porphyry" has phenocrysts in a fine-grained or aphanitic groundmass, while a "porphyritic" rock has phenocrysts in a phaneritic or

The thin sections of the porphyry show rather typical structural, textural, and mineralogic features (see fig. 3). The groundmass is composed of fine-grained quartz, feldspar, and mafic minerals. The average grain size is about 0.8mm in both thin sections examined. The grains are interlocking and have a rather wide range of size. The phenocrysts are generally slightly corroded. In a number of instances, biotite appears to be replacing hornblende in parallel arrangement - a reaction which is predicted by the Bowen reaction series.

Fig. 3.- Photomicrograph of the quartz monzonite porphyry.

Following crystallization, deuteric alteration and weathering produced some chlorite and epidote from the mafic minerals, and a little sericite and kaolinite from the feldspars.

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granitic groundmass. The distinction may be of significance in relation to ore deposits. Stringham (1958 and 1960) has noticed a distinct connection between "passive" intrusive porphyries (not porphyritic intrusions) and significant mining districts in the Basin and Range. Stringham believes that the presence of "passive" porphyries in an area is a good guide to ore.

Aplite

Aplite occurs irregularly in the larger phacolith and probably elsewhere. The rock weathers to tan-gray, massive blocks, quite similar in appearance to the porphyry. On fresh surfaces, the aplite is a massive, uniformly fine-grained gray rock which looks very much like a sandstone. Orthoclase and quartz constitute 99 per cent of the rock, with one per cent albite plagioclase (An_{06}). Biotite, hornblende, augite, apatite, zircon, and sphene occur in trace amounts.

Alteration products observed in the aplite are similar to those observed in the porphyry, with the exception that no chlorite was seen, probably due to the fact that there is much less magnesium and iron in the aplite.

Inclusions

A few small well-rounded dark inclusions of monzonite composition occur in the south (or lower) edge of the main phacolith, very near the contact between the igneous and the sedimentary rock. The inclusions all have a "salt-and-pepper" appearance, although the grains are too fine to distinquish anything but hornblende in hand specimen. The estimated modal analysis of a typical specimen is given below.

Orthoclase	45 %
Plagioclase $An_{\approx 32}$	32
Hornblende	20
Magnetite	2
Others	1
	100 %

Johannsen no. 2210"

In thin section the inclusions are seen to be fine grained with a very ragged overall appearance (see fig. 4). The average grain size is

0.4 mm, with a maximum crystal size of one mm. The crystals are deeply embayed and generally anhedral. The plagioclase is generally untwinned or just faintly twinned. Kaolinite, sericite, and chlorite are present as alteration minerals.

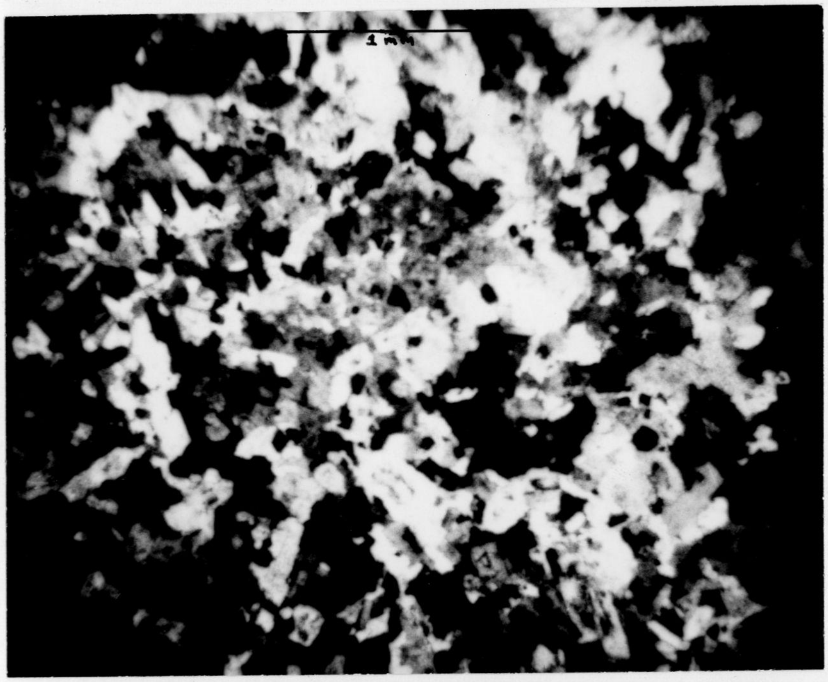

Fig. 4.- Photomicrograph of an inclusion from the lower edge of the major phacolith.

The presence of the inclusions, or xenoliths, near the bottom edge of the phacolith is significant. The xenoliths presumably are pieces of some different, more mafic, rock type which were broken off and carried up from below. The greater specific gravity of the mafic rock kept the fragments near the lower edge of the phacolith. The rock fragments probably reacted extensively with the magma, as all of the inclusions are now well-rounded and smooth. However, the fragments did retain their identity, for they easily can be broken out of the porphyry leaving clean, smooth cavities.

DESCRIPTION OF STRUCTURAL TYPES

Phacoliths

The two major intrusive bodies, located at (0N, 100W) (pl. 1) and (0N, 400W) (pl. 1), have been termed phacoliths by the author. The bodies are generally concordant, and there is marked thickening toward their centers. They occupy the crest of a northeast-plunging anticline. As neither body is wholly concordant, the phacoliths are not "pure" phacoliths. Nonetheless, the term phacolith is used in this paper for these two intrusions rather than the general term "stock" because the term phacolith emphasizes the observed relations between the igneous bodies, the sedimentary strata, and the fold.

The mode of intrusion of the bodies was probably both forceful and passive. The forceful nature of the intrusion is indicated by the strata separated by the porphyry; near the edges of the igneous bodies this separation of sedimentary beds is small, while near the center, the distance between the same beds is quite large. Billings (1954, p303) points out that some geologists believe that phacoliths are intruded passively into cavities which form as folding proceeds. However, his conclusion that it is probable that the magma is under pressure and forces its own way is applicable in this case; it is difficult to imagine a cavity 400 by 900 feet in lateral dimensions opening as a result of only tensional stresses, especially in such a small fold. The passive nature of the intrusion is shown at, for instance, (100N, 900W) (pl. 1) and (200N, 200W) (pl. 1). At these places, the sedimentary beds have been crosscut and removed, either by assimilation into the magma or stoping. Both of these processes occur in passive intrusion, where the magma is supposed to work its way gradually into a rock mass, making room for itself by other means than forcefully pushing the rock aside.

It seems probable from the spatial relationship that the two phacoliths are connected at a shallow depth.

Stock

An irregularly shaped stock is located at (800S, 800W), in the bottom of two coalescing gullies. This is a topographic position exactly opposite to that of the phacoliths. As the rock is virtually identical with the rock of the phacoliths, the immediate conclusion is that the stock has just recently been exposed, and the irregular outline presented in the field represents the very top of a mass which presumably increases in size with depth. This conclusion is well supported by an adit which was driven into the center of the mass, presumably to intersect certain mineralized areas beyond the porphyry to the west (see geologic map and cross-section A-A', pl. 1). Although the horizontal projection of the westernmost face of the adit lies 80 feet on the limestone side of the surface contact between the limestone and the porphyry, the adit is completely in porphyry. A crosscut southward produced similar results.

Sills

At least three sills are exposed in the study area - two fairly long ones between the stock and the larger phacolith, and one small one (not mapped) north of the larger phacolith. The rock of the sills resembles the porphyry of the stock and phacoliths, except that it has fewer, smaller phenocrysts. The major sill (300S, 500W) (pl. 1) is from four to seven feet wide, and is traceable for almost 1000 horizontal feet parallel to the southern edge of the large intrusion to the north. The sill is widest near the southeastern end, where it bends southward. The other sill between the stock and the phacolith is located just south and below the west edge of the major sill. Both sills show selvages with coarser rock in the centers. The third sill is scarcely six inches wide and is located near the top of the section exposed in the roadcut north of the larger phacolith at (250N, 450W) (pl. 1).

Dikes

The principal dikes extend from the smaller phacolith, and lesser dikes extend from the stock. The two dikes of the phacolith protrude from both ends like great outstretched arms. Both dikes are about 300 feet long, but the one extending to the north is much thicker and stands high above the surrounding less resistant sediments. The rock is virtually identical with the porphyry of the sills, and it shows a similar selvage. The dikes of the stock are smaller than the dikes of the phacolith, but in other respects the two sets of dikes are very similar.

The reason for the intrusion of dikes is not obvious, since the intrusion of concordant igneous bodies or discordant, roughtly equidimensional igneous bodies seems to be favored in the immediate area. One possibility, at least for the large dike off the north end of the phacolith, is that the magma followed a zone of weakness created by fracturing during folding. The large dike trends almost parallel with a small fault several hundred feet to the west.

Smaller Apophyses

A number of small intrusive stringers and nodes occur in the study area, mainly between the stock and the phacoliths. Most of these are shown on the geologic map (pl. 1). They range in size from four feet by four feet to 150 feet by 70 feet in maximum dimensions. The rock type is identical to that of the phacoliths.

LOCALIZATION AND AGE OF THE INTRUSIONS

From field observations, the following conclusions have been made concerning the localization and age of the intrusions.

1. The igneous rocks were intruded at a relatively shallow depth - very possibly within a mile of the surface. This is indicated both by the stratigraphy in the area and by the nature of the intrusions themselves. It seems probable that in the area of the Star Range there was a maximum of 4500 feet of Triassic and Jurassic sediments deposited, and it is possible that no or little Cretaceous sediment was deposited. Several periods of post-Jurassic erosion occurred, separated by deposition of volcanic rocks in probably mid- or late-Tertiary time. If the rocks in the study area are Permian and Pennsylvanian, as shown by Baer (1962) on his geologic map, then the rock cover at the time of intrusion was probably much less than one mile thick. If the country rock is Mississippian, then the rock cover might have been several thousand feet thicker at the time of intrusion.

The texture and structures of the intrusions support the conclusion that the rock solidified at a relatively shallow depth. Turner and Verhoogen (1960, p331) divide granitic intrusions into three classes. The

Rebel area intrusions fit the class of "minor intrusions" which "appear to have consolidated at relatively shallow depth - in some cases less than a mile below the surface."

2. The main underlying igneous mass is probably relatively large and near the present surface. It has been previously mentioned that a large number of igneous bodies of various sizes are exposed at the surface. The smaller bodies (stringers, nodes, and sills) probably could not have been injected any great distance from the source mass without solidification due to cooling. The relatively great concentration of igneous bodies in a distinct and limited area also indicates the presence of a large, near-surface igneous mass. The extreme increase in cross-sectional area with depth of the stock has already been noted.

A large intrusion of similar composition (Baer, 1962) occurs just north of the Rebel area. The Rebel intrusions probably connect with or are directly related to this large intrusion.

From these considerations, an observation may be made in passing: if a much larger igneous mass does exist at shallow depth, there is a better possibility that an adjacent contact metamorphic (or other type) ore deposit of good size also exists within striking distance of the surface.

3. The mapped intrusions probably formed during or after folding and were intruded along zones of weakness at or near the crest of the major fold. The relation of the igneous rock to the fold is shown in fig. 5. The folding was probably due to compressive stresses. Stokes and Heylmum (1962, p21) state that "thrusting and extensive folding" occurred "during the climax" of orogenic activity in Cretaceous time. Thrust

faults of the type produced by this orogenic activity are generally considered to result from near-horizontal compressive stresses. As a result of active compression along one plane, tensional forces are created normal to the plane (Billings, 1954, p96). The strain at the fold axis created by the bending of the strata further minimizes the compression in the axial plane and normal to the fold axis. Thus a fluid magma, if present, would be concentrated at or near the axial plane. The magma (which is under pressure from below or it would not be moving upward) would expand to the greatest extent against the inclosing rock in the axial plane alone. Figure 5 shows that this is indeed the situation in the Rebel area.

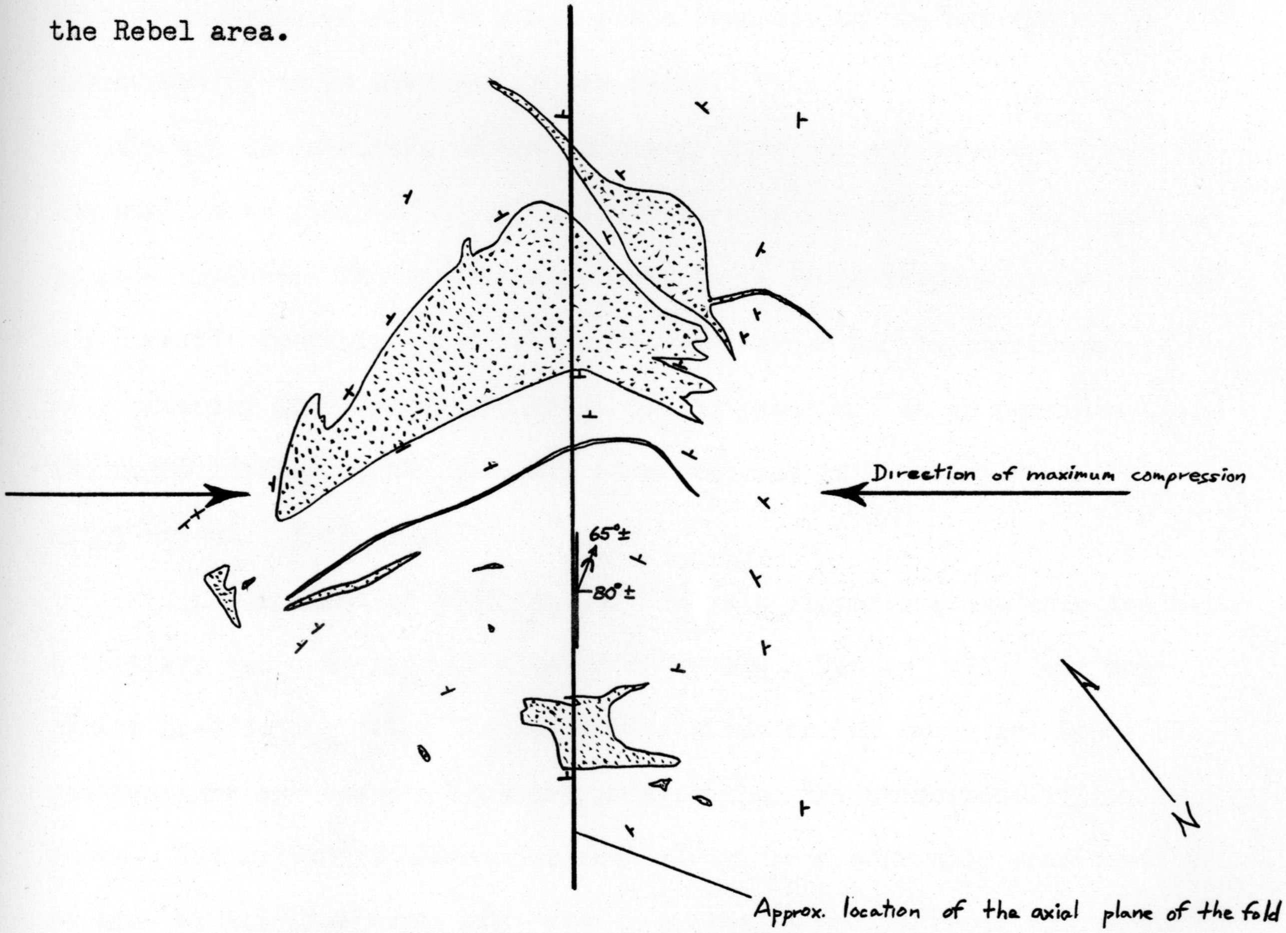

Fig. 5.- Relation of intrusions to the major fold northwest of the Rebel mine.

It is also possible that intrusion occurred substantially after the major period of folding, believed to be in Cretaceous time. The strain resulting from prior folding would tend to localize the magma in the axial plane.

Another possibility, which the author considers untenable, is that intrusion of magma preceded major folding. This possibility is not borne out in the field, for while shear faults in relatively competent beds such as sandstone are common, especially near the axial plane of the fold, no breaks at all were observed in the much more competent quartz monzonite. In addition, it would be a remarkable coincidence if the major fold in the area were developed with an axial plane transecting the intrusions as symmetrically as is observed in the field.

4. The age of intrusion of the porphyry, from the evidence available in the small area studied, is probably Cretaceous (medial?) but may possibly be mid-Tertiary. The orogeny described above is believed to be a part of the Laramide Orogeny, which in its broadest sense may be considered to have extended from Jurassic time until the present. It is possible that the major folding in the area may have occurred in Tertiary time, in a minor renewal of orogeny.

Consideration of previous work reveals supporting evidence for both a Tertiary and a Cretaceous time of intrusion. Butler (1913) and many others have demonstrated that many intrusions in the Basin and Range of southwestern and western Utah are younger than the ubiquitous volcanic rocks. The volcanics themselves have always been generally considered to be mid- to late-Tertiary, and recent age-dating by Armstrong (1963) and others seems to confirm this. Butler (1913) showed in his work in the

San Francisco region that quartz-monzonite and granodiorite bodies are intrusive into volcanics in the San Francisco and Beaver Lake Mountains, and also in the western edge of the Star Range. There are no volcanics in the eastern half of the Star Range or the Rocky Range five miles north of the Star Range. However, owing to the similarity of all intrusive rocks in the region, it was tacitly assumed that the intrusions of the Rebel and Vicksburg mines of the Star Range and the Old Hickory mine of the Rocky Range were post-volcanics also. However, the one age determination (Pb-α) available to the writer gives an age of 97 million years, or mid-Cretaceous, for the intrusion of the Old Hickory mine area (Whelan and Odekirk, 1963).

CONTACT METAMORPHISM

GENERAL STATEMENT

The igneous intrusions in the Rebel mine area had widespread and varied contact metamorphic effects upon the surrounding sedimentary rocks. The contact metamorphism may be divided into isochemical and metasomatic metamorphism. Isochemical metamorphism produces recrystallization (changes of mineralogy and/or texture) with negligible gain or loss of material. Metasomatic metamorphism results in changes which are caused by addition of material. The distinction between isochemical and metasomatic metamorphism is important; if an exposed series of metamorphosed rock is shown to be a result of only recrystallization of the original rock constituents, then the chances for an ore body at reasonable depth are much less than if the series were a result of metasomatic introduction of material. The contact metamorphism in the Rebel area was investigated with this distinction in mind.

TYPES OF CONTACT METAMORPHIC ROCKS

Five types of contact metamorphic rocks have been recognized in the Rebel mine area. These are listed below together with locations.

Types of contact metamorphic rocks in the Rebel mine area.

Widespread

1. Recrystallized and bleached limestone. All of the limestone in the area has been recrystallized, and most of the limestone has undergone bleaching.

2. Silicified sandstone. The "unnamed" quartzite unit above the Rebel limestone was probably formed from a sandstone by the addition of silica from magmatic fluids.

Localized

3. Skarns, or rocks rich in calc-silicate minerals, especially green garnet, which formed from carbonate rocks by addition of elements. Skarns are located irregularly on the sides of the major intrusions and are often associated with the minor intrusions. There is also one four-foot by eight-foot patch of skarn at the very top of the Rebel limestone (50N, 950E) (pl. 1). The skarn zones around the phacoliths have been indicated by dotted lines on the geologic map (pl. 1). The stock has a skarn zone, chiefly on the southeast side of the porphyry, which was not indicated on the map.

   In the Rebel area there are two types of skarns.
   a) Skarns barren of ore minerals.
   b) Skarns containing ore minerals of Fe, Cu, W, and Mo. This type of skarn is commonly called tactite.

4. Hornfels, formed from generally impure fine-grained sandstones and siltstones. The hornfels occur in a series of beds north of the larger phacolith, and also in irregular, apparently disjointed patches centering at (800S, 300W) (pl. 1) on the geologic map. All of the hornfels units are mapped.

5. Veinlets of quartz, iron ore, calcite, and calc-silicate minerals, chiefly grossularite, in porphyry. A few veins were noted in the vicinity of (200N, 400W) (pl. 1).

Type one is believed to be a result of isochemical metamorphism, while the other types are a result of metasomatic metamorphism.

GENERAL NATURE AND EFFECTS OF CONTACT METAMORPHISM

Introductory Statement

The metamorphism in the area is believed to have resulted from the passage of fluids, largely water, through rocks at high temperatures and pressures. The fluids were contained in the magma, and as the magma cooled and crystallized, water and other volatiles were driven into the surrounding rock, eventually probably finding their way to the surface. These fluids were important in the process of metamorphism for two main reasons. 1) The chemical reactions of metamorphism were speeded due to the presence of a highly active medium (the high-temperature fluid in the rock pores) which allowed ions to diffuse rapidly and equilibrium to be established quickly with respect to new chemical and temperature conditions. 2) The fluids themselves carried appreciable amounts of numerous cations, which were deposited as soon as chemical conditions became favorable. Generally conditions became favorable as soon as the fluids left the cooling igneous body and entered the surrounding rocks. The formation of virtually pure calc-silicate skarns in thin shells immediately adjacent to the igneous intrusives is good evidence that the limestone was highly reactive to fluids carrying cations away from the igneous mass. Yet, as shown on the geologic map (pl. 1), the skarns do not completely or uniformly envelop the various intrusions. In addition, the skarns are not even uniform in composition, but fall into two distinct groups and may even be subdivided further.

There are four possible explanations for the uneven distribution of skarns around the intrusions. 1) The fluids may not have reacted equally with the enclosing rock. This reason is discounted because the apparent uniformity of the limestone (in which the skarns are developed) indicates that reactions to form skarns would proceed equally well in any portion of the limestone. 2) The fluids may have entered the wallrock only at certain places, where the skarns are now found. 3) Fluids may have entered the wallrock at other places around the igneous body, but only the fluids which passed through the wallrock where skarn is not seen had cations to deposit; the other fluids were barren of cations. Both 2) and 3) seem equally "plausable," with possible arguments for and against each theory. It may possibly be that both explanations hold for the formation of skarns in the Rebel mine area. The major objection to theory 2) is the lack of an apparent reason for localization of the fluids. In many areas around the intrusives, such as at (200N, 200W) and (300S, 200W), one would definitely expect the development of skarns by theory 2), but there is no skarn zone. The problem with theory 3) is the necessity for an inhomogeneous fluid that was derived from an apparently homogeneous magma. 4) The fluids may have been given off by the magma in several "stages," and because of various reasons each "stage" of fluid had a different content of reactive cations. The "stages" may represent particular durations of time in which the escaping fluids had a particular cation composition, or they may represent actual discontinuous pulses of fluid from the cooling igneous masses. The first three explanations tacitly assume one fairly short burst of fluids from the cooling and solidifying magma. This is more or less the assumption in most explanations of contact metamorphism; the fluids were given off by the magma at some one stage of crystallization, and if they had the proper constituents then ore deposits were formed. If not, then no ore deposits were formed.

While evidence for theory 4) is not conclusive, to the writer this explanation best fits the observed metamorphic rocks in the Rebel mine area. The probable sequence of the "stages" with field evidence is as follows:

1. During or slightly after the implacement of the main magmatic mass at depth and the intrusion upward of the phacoliths, etc., large amounts of generally barren fluids were exuded from the magma. These fluids caused recrystallization and bleaching of the carbonates and possibly recrystallized and silicified the sandstone unit stratigraphically above the Rebel limestone. This latter point is far from certain, however. It should be restated here that the exposed igneous rocks probably represent the highest or very nearly the highest penetration of magma in the immediate vicinity.

2. After cooling of the upper outliers of the magma had progressed sufficiently to allow the formation of at least a shell around the intrusions presently visible in the Rebel area (assuming conventional solidification - from the outside in), a second "stage" of fluids, more limited in volume and scope but containing cations of various elements, made its way upward from the magma at depth and possibly outward from the still semi-molten center of the larger phacolith. These fluids passed more readily through the siltstone beds in the limestone than the recrystallized limestone. All of the argillic and arkosic siltstone units in the Rebel limestone were converted to uniform hornfels by a combination of recrystallization and metasomatic metamorphism, but the formation of skarn from limestone was much more localized. It appears that fractures and "permeable surfaces" that were created by the contraction of the cooling intrusives provided the means for cation-bearing fluids to rise

and in the process form skarn zones. This could explain the seemingly peculiar arrangement of skarn zones around the intrusions. Zones of tension and thus permeability would be expected at the crests of the convex and concave sides of the major phacolith and along the concordant sides of the phacoliths (where bulging of the sediments had taken place). Tension would not be expected in those areas where passive stoping has produced a complex interrelationship of igneous and surrounding rock (300S, 200W) (pl. 1). The contact is irregular enough to allow cooling without major, continuous fracturing, and very possibly without fracturing at all. It should be noted that the skarn zones - indicated by dotted lines on the geologic map - are located precisely where they would be expected by this theory. It seems to the writer that if the skarn-forming fluids were given off by the intrusions themselves as exposed on the surface (i.e. if the movement of the fluids were radially outward, in this case approximately horizontal, rather than primarily upward parallel to the igneous rock-limestone contacts, as suggested), then the exact opposite should be noted. That is, the formation of skarns should be most pronounced at (300S, 200W) (pl. 1), where the magma was most reactive with the limestone, and least pronounced where the intrusions are concordant with the limestone.

In regards to the correlation between passive intrusion and lack of skarn, an apparent exception exists in the case of the stock and nearby area. Skarn zones were noted in the vicinity of (800S, 800W) (pl. 1) on the east side of the stock, and also at (900S, 500W) (pl. 1) where the skarn appears to be divorced from igneous rock. However, as previously noted, it is believed that the stock represents the very top of a large, igneous mass, very possibly the mass from which part (or all) of the second stage fluids were derived. It is also believed that the skarn zone at (900S, 500W) (pl. 1) in which scheelite is found lies directly above igneous rock, probably a high part of the roof of the stock.

At least some of the skarns formed after solidification of the intrusions had begun, because veinlets of calc-silicate minerals, calcite, and quartz were observed at (200N, 400W) in porphyry (fig. 6).

In certain areas, the skarns contain early-formed molybdenum-bearing scheelite. Locally magnetite and specular hematite are present in the skarns. Magnetite is found near the stock, while specular hematite is in general associated with skarns at higher elevations. One small specimen of chalcopyrite was seen. The paragenetic sequence is given in the section on ore deposits (p.

Fig. 6.- Veinlet of garnet and other minerals in porphyry.

3. After formation of the skarns and hornfels by second-stage fluids at relatively high temperatures, a third, relatively minor, stage of fluids deposited the copper mineral malachite (with a very little azurite) at relatively low temperatures. The malachite fills cracks in massive skarns which had fractured as a result of cooling or minor tectonic or readjustment forces. Principally because of the lack of the sulfides pyrite and chalcopyrite in the contact metamorphic rocks, the writer is inclined to believe that the malachite was primary (magmatic) rather than secondary (supergene).

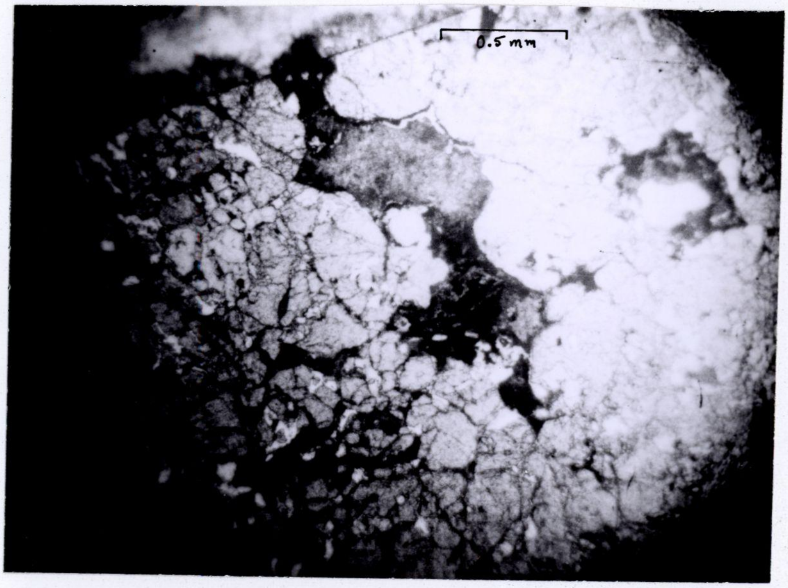

Fig. 7.- Photomicrograph of malachite in skarn from (250N, 150W) (pl. 1).

A number of specimens from several different areas were collected which provide an interesting "confirmation" of the basic principle of the entire discussion above - that the chief agent of metamorphism was water. Figure 8 shows a specimen of scheelite-bearing skarn from the prospect as

(900S, 500W) (pl. 1). The primary feature is the crystal-rich vug, of the type called by miners a "watercourse." The increase of hydroxyl-bearing minerals toward the vug is evident in this specimen. As temperature falls in a hydrothermal system, the stability of hydrous minerals (e.g. epidote) over anbydrous minerals (e.g. garnet, diopside, scheelite) increases. One mineral formed over another mineral as the temperature dropped. The last mineral formed from the fluids was quartz, the free-growing crystals in the vug. The vug shows quartz in zoned single crystals and botryoidal masses of tiny crystal points. Figure 9 shows a "watercourse" specimen which was collected as float from just south of the larger phacolith. This particular specimen shows well-zoned quartz crystals, indicating concentric crystal growth, presumably from solutions.

Description of the Types of Contact Metamorphic Rocks

Type 1 - Recrystallized and bleached limestone. The limestone in the Rebel mine area has been entirely recrystallized and generally bleached. Recrystallization is evident on fresh surfaces of the limestone, whether dark or light in color. The limestone shows a glittering appearance indicative of recrystallization of many small grains into larger grains capable of showing cleavage faces. The resultant size of the calcite grains is undoubtable a function of the intensity and duration of the fluids which caused recrystallization. The average size of the calcite grains at a moderate distance from the intrusives is under 1mm. The bleaching of the limestone from dark gray to pure white is probably a result of the removal of elemental carbon which is present in the calcite lattice in minute amounts (Park, 1964, p47).

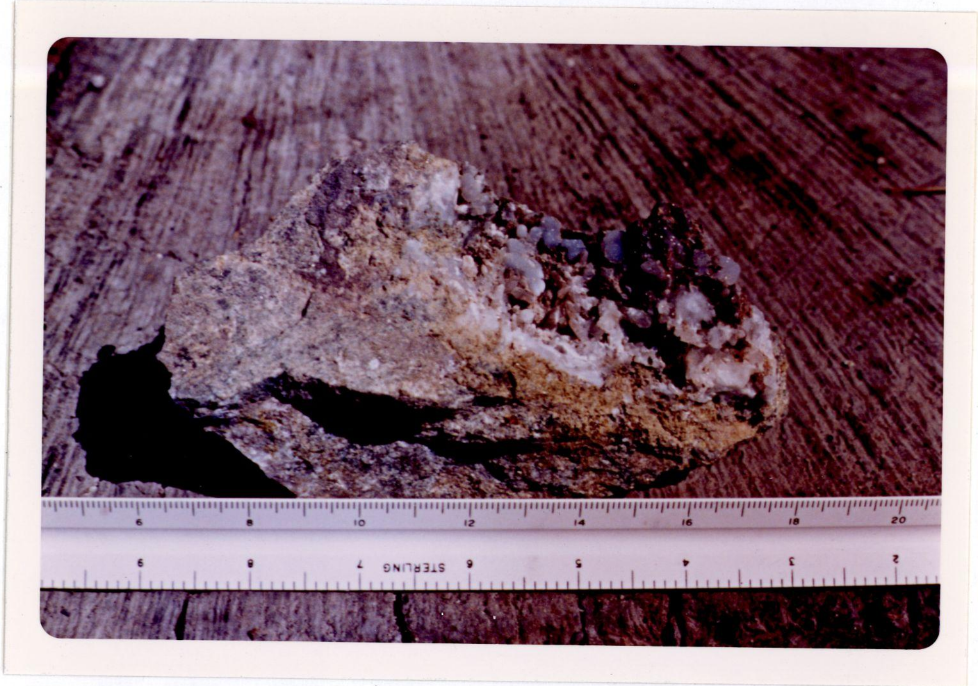

Fig. 8.- Skarn from the scheelite prospect at (900S, 500W) (pl. 1).

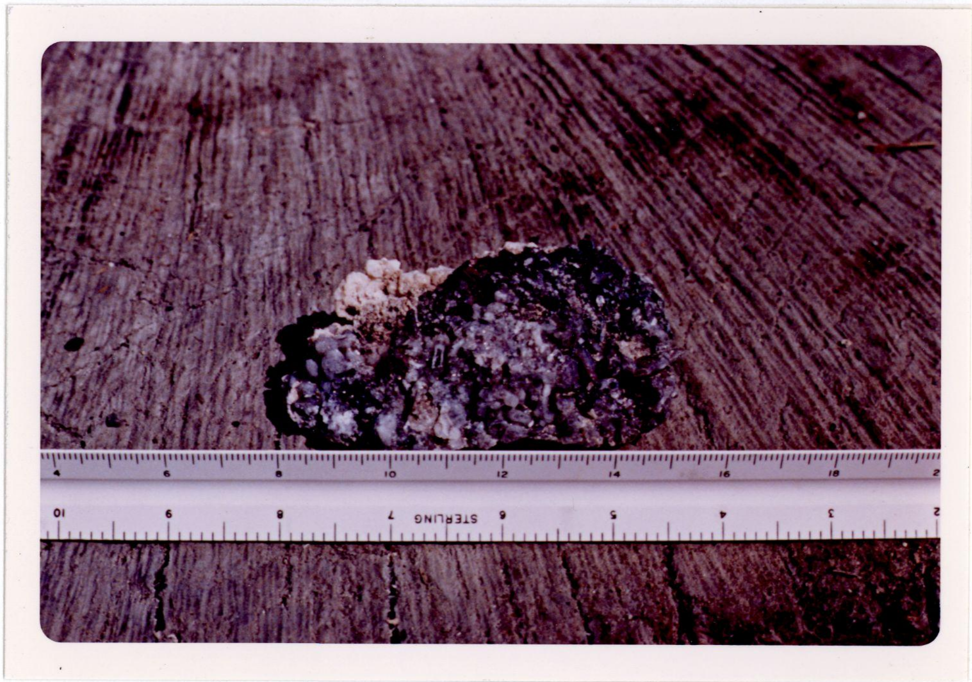

Fig. 9.- Well-zoned quartz crystals from near (300S, 150W) (pl. 1).

Type 2 - Silicified sandstone. The introduced silica formed overgrowths on the original quartz grains. The resulting quartzite is almost 100 per cent quartz.

Type 3 - Skarns.

Textural and Mineralogic Features.

Two types of skarns were recognized, those barren of ore minerals and those containing ore minerals.

The barren skarns comprise perhaps 90 per cent of the skarns exposed in the study area. Mineralogically these skarns are simple; the dominant mineral is grossularite garnet. The garnet is commonly massive and a dull yellowish green, although occasional small crystals of darker green garnet are seen in vugs, on bedding-plane surfaces, and as free-growing crystals in calcite. Less important minerals include calcite, diopside, tremolite, quartz, epidote, and chlorite, in approximate order of abundance. Except for the calcite, the lesser minerals are usually only present as microscopic crystals.

A small part of the barren skarns are composed almost wholly of coarse white bladed wollastonite. It is interesting that no wollastonite was observed in any of the twelve other thin sections of skarns and hornfels examined, which suggests that for this area the chemical conditions necessary to form wollastonite (probably the lack of magnesium and iron) were such that no or very little garnet, diopside, or tremolite could form. The wollastonite skarn was collected from the working face of the adit at (250N, 50W) (pl. 1).

The ore-bearing skarns comprise the remaining 10 per cent or so of the exposed skarns in the Rebel mine area. In marked contrast to the barren skarns, the ore-bearing skarns are complex in both mineralogy and texture. Although the two types of skarns are not differentiated on the geologic map (pl. 1), a rough idea of the location of the ore-bearing skarns may be gained by noting the locations of the prospect pits and shafts around and near the intrusions.

For the purpose of this study, ore minerals include the metallic oxides of iron - specular hematite and magnetite, certain minerals of copper - malachite and a little chalcopyrite and azurite, and the typical contact metamorphic mineral of tungsten-scheelite.

By far the most abundant ore minerals are specular hematite and magnetite. Specular hematite is widespread as shiny metallic grey tablar crystal plates. The magnetite, however, is generally confined to the vicinity of three prospect pits just northwest of the main stock, at (700S, 1000W) (pl. 1). A typical occurrence of magnetite is in layers of small lustrous black crystals from one-half to two inches thick separated by thin white bands of coarsely crystalline calcite.

The copper minerals are also widespread. Malachite occurs as microscopic crystals in massive garnet skarn. The one piece of chalcopyrite observed came from a small prospect at (0N, 200W). What little azurite that is present occurs in coarse calcite, as would be expected by its CO_2 content (higher than in malachite).

The scheelite occurs in several localities. The mineral most commonly occurs as large, embayed white crystals in coarse skarn.

Other minerals of this type of skarn are grossularite and diopside, with lesser and very variable amounts of calcite, tremolite-actinolite, quartz, epidote, chlorite, adularia, and allanite, in approximate order of abundance. The minerals of the ore-bearing skarns are usually in larger and more "showy" crystals than the same minerals of the barren skarns. Garnet and calcite are especially favored. Dark green euhedral grossularite crystals to one-half inch across grow in coarse calcite at (150S, 800W) (pl. 1) and elsewhere. Quartz is occasionally found as small (under one inch) terminated crystals in vugs (see figs. 3 and 4). Further details on occurrences are given in the section on mineralogy.

Structural Relationship of Skarns to Recrystallized Limestone

Both types of skarns tend to conform to bedding in a general way, but examination of the skarn zones in detail shows that minor transgressions of bedding in the limestone are very common. A belt of skarn may be roughly parallel to the bedding for a short distance and then abruptly blossom irregularly into the limestone beds. It was noticed that in almost every case the actual calc-silicate mineral (usually garnet) was surrounded by a shell of very coarse calcite. The calcite in these shells undoubtedly represents very coarse recrystallized limestone.

It was also observed that the skarn zones in some cases formed only in certain limestone zones or layers, leaving apparently identical separating limestone virtually untouched. This was best seen at (150S, 700W) (pl. 1). The writer believes that the fluids migrated along the most permeable "tension planes" (see p.29) which were probably relict bedding planes in the limestone. From these planes, the fluids spread out in both directions creating the observed zones of calc-silicate rock.

Type 4 - Hornfels. The hornfels were developed from various types of argillic and arkosic siltstones. Their occurrence and general physical characteristics are discussed in the general description of the Rebel limestone on p.15. Of interest here is the probable addition of minor amounts of various elements by metasomatic metamorphism which helped to correlate the dark-colored hornfels north and south of the larger phacolith.

Hornfels similar in appearance to the uppermost and thickest hornfels north of the larger phacolith were observed in three discontinuous bodies in the general vicinity of (800S, 300W) (pl. 1). The major difference in the hand specimen of the two hornfels is that the hornfels south of the major phacolith are more iron stained on weathered surfaces. In fact, this iron staining is intense enough in parts of the northernmost of the three hornfels bodies that a good-sized prospect pit was sunk even though the rock is barren of ore minerals. Thin sections of typical specimens from both hornfels areas showed that at least the gross petrographic features are similar. Both hornfels are composed of quartz, with lesser amounts of sericite, chlorite, and opagues (mostly magnetite). Differences seem to be in the constituents which could have been added by metasomatic metamorphism. The hornfels from (800S, 300W) (pl. 1) have about five per cent magnetite and two per cent tourmaline. The magnetite is mostly in veins and stringers. The tourmaline is present as a large number of small, euhedral crystals, of the iron-rich variety schorlite. The hornfels from north of the larger phacolith contain two per cent opagues (magnetite?) as disseminated specks, and less than one per cent schorlite. Because the general features of both hornfels are similar, the specimens from both hornfels were examined by x-ray fluorescence to determine if there is a similarity in minor-element constituents as well.

A piece of the hornfels from (800S, 300W) (pl. 1) that was not particularly veined by magnetite was selected. The agreement in minor element constituents was remarkably close, as shown below in table 1. The machine was set to read peak heights logarithmically, with 100 units equal to full scale (maximum) deflection. Thus a peak height of 70 units indicates an abundance for that element much greater than seven times that for the same element which has a peak height of ten units. The strongest peaks, the Kα peaks, were used for comparison as they provided the greatest intensity contrast.

Table 1.- Comparison of Kα-radiation peak heights (logarithmic) of elements in two different hornfels.

	hornfels from (800S, 300W)	hornfels from (250N, 400W)
iron	73.0	69.0
copper	18.5	20.0
titanium	11.0	10.5
zirconium	9.0	5.5
nickel	4.5	9.0
strontium	5.0	5.0
zinc	2.0	3.0

The similarity between all of the measurable elements suggests that the two hornfels were originally of very nearly the same minor element composition (i.e. they were probably in the same bed), and in addition the two hornfels acquired the same elements in about the same quantities during metasomatic metamorphism. The light elements (those lighter than titanium) were not detectable, but it is believed that boron was added in appreciable quantities to both rocks, because of the large number of euhedral crystals of tourmaline observed in thin section.

Type 5 - Veinlets of calc-silicate minerals, etc. in porphyry (see fig. 6). The veinlets occur in small numbers in and near the road cut at (250N, 400W) (pl. 1) and perhaps elsewhere. The veinlets are usually less than one-half inch wide, but they may be continuous for at least ten vertical feet along the porphyry-skarn contact. The veinlets probably do not extend very far into the intrusions.

The veinlets are composed of garnet, calcite, quartz, hematite, and epidote, in approximate order of decreasing abundance. Two general types of veins were noted, those mostly garnet and those mostly quartz.

The wallrock of the veinlets is always altered and bleached. Thin sections of the two types of veinlets show that in general calcite and epidote are added while magnetite and ferromagnesian minerals are corroded. The width of the alteration zones is usually one to two times the width of the veinlets.

GEOLOGIC STRUCTURE

Folds, faults, and fissures are important in the Rebel mine area. As previously mentioned, folding localized the intrusion and probably did much to localize the skarn zones in the limestone. The Rebel fissure and the faults were of primary importance in providing a locus for the deposition of ore. Several sets of joints of no recognized significance occur in the area.

FOLDS

The major folding of the sedimentary rocks in the general area resulted in a homoclinal structure dipping to the east from 25 to 70 degrees and extending the entire length of the Star Range (Baer, 1962).

In the Rebel area, this uniform homocline is twisted back on itself to form a tight anticline which plunges steeply to the north, as indicated on the geologic map (pl. 1) and in figure 5. The writer believes that the fold was probably caused by compressional stresses which were greatest in the (present) east-west direction and least in the north-south direction. The fold is characterized by a large amount of plastic flow of the weak limestone, a combination of plastic flow and fracturing of the siltstone beds, and fracturing of the brittle sandstone beds. Deformation in the limestone is especially noticeable adjacent to thin sandstone beds, where the sandstone beds fractured and were offset during folding, while the beds of limestone flowed but did not fracture.

FAULTS

Faults were observed in the Rebel mine area at (1100S, 0W) (pl. 1) and (750S, 1000W) (pl. 1). More is known about the fault at (1100S, 0W) (pl. 1) because it is the larger of the two, has the greater stratigraphic displacement, and in addition is exposed in the underground workings of the Rebel mine and surrounding prospects. The fault strikes N20-25W and dips 75 degrees to the west. The dip was measured underground on a uniform striated surface of limestone fault gouge. The direction of the movement could not be determined with certainty. The minimum movement, equal to the observed displacement of the beds, is 260 feet, but the actual movement was probably quite a bit more. The fault shows at least one branching fault off the major fault line with what appears to be a horse of limestone in between. The branching fault surface is well exposed in the deep prospect at (1400S, 200E) (pl. 1). The dip of the branching fault is 45 to 60 degrees to the east.

The second and smaller of the two faults strikes about N60W. The dip is uncertain but may be steeply to the east, as that is the way the mineralized rock appears to dip in the two flanking prospect shafts. The direction of the movement is not known.

FISSURE

Cutting the faults at about a right angle is the main ore fissure of the Rebel mine (fig. 10). The fissure is traceable through prospects for at least 3200 feet, although there are occasional long stretches where no evidence of the fissure appears on the surface. The strike is about N70E and the dip appears to be steeply to the south, at least on the surface. However, underground the ore zones dip to the north as little as 40 degrees (see pl. 2).

The general impression one gets is that the fissure was a result of uniform tensional stresses which in homogeneous rock would have resulted in a clean straight fissure striking perhaps N75E and dipping to the north at a steep angle. However, because the limestone beds (in the immediate vicinity of the Rebel mine) dip to the south at 55 or 60 degrees and strike about N60E, the fissure formed parallel to the bedding planes for a short distance and then "jumped" across a few feet of limestone beds so that the overall effect was about N70E, the observed general trend of the fissure. This is well shown in the surface map of the Rebel mine (pl. 2). Likewise in the vertical plane the fissure formed parallel to the bedding for a short distance (as observed in the surface stopes) and then broke sharply across the limestone forming relatively flat-lying fissures dipping to the north, such as those observed in the underground stopes off of the main adit (pl. 2).

Fig. 10.- Rebel fissure looking east from (1100S, 200W).

The relationship between the faults and the cross-cutting fissure is not definite. Because the fissure crosses both faults with apparently no offset, it is assumed that fissuring was post-faulting. It is also possible that the faults are offset by the fissure, as neither of the faults was definitely traced across the fissure. Complicating the matter is the presence of a very finely divided limestone fault gouge in both the fault and fissure zones of the main Rebel workings. The host rock and gangue of the ore are limestone in the form of a brown, coarsely crystalline calcite. This calcite was partially to completely replaced to form the ore bodies, and yet there seems to have been no ore formed in the calcite fault gouge, which should have been more reactive due to the very fine particle size of the calcite. As practically all of the barren main adit (320 feet long) is in striated and grooved limestone fault gouge, it seems that at least some of the ore should have formed in the gouge, if the fault gouge were present before mineralization. The probable explanation is that the fault gouge was formed by relatively minor post-mineral movement along the main fault and also parallel to the ore-bearing fissure.

The age relationship of the faults and fissure to the intrusives is not at all certain. However, evidence from nearby areas indicates that at least the ore fissures are post-intrusion. Townsend (1950, 1953) has found this to be the situation in both the Vicksburg and Harrington-Hickory areas.

JOINTS

Joints are well developed in the larger phacolith and are developed to a lesser degree in the surrounding rocks. From the few orientations obtained, there are at least four reasonably well-defined joint sets in the area, only three of which are present at any one location. Of these four, two seem to be unvarying and ubiquitous. The first set strikes N5E to N5W and dips 35-50 degrees west. The second set strikes N60E to N75E and dips 65 degrees north to almost vertical. The similarity between the orientation of the second prominent joint set and the orientation of the Rebel ore-bearing fissure is interesting.

CORRELATIONS BETWEEN THE FISSURES AND FAULTS OF THE REBEL MINE AREA AND SURROUNDING AREAS

Fissures

The Rebel fissure is one of a large number of ore-bearing fissures which are found in all parts of the Star Range. However, the orientation of the fissures appears to be controlled by local conditions, as the fissures have a number of different attitudes. From the works of Butler (1913) and Townsend (1950, 1953), it appears that there are three primary orientations of ore-bearing fissures in the Star district: N50-70E, which dip vertically to steeply to the northwest; E-W, which dip vertically to steeply to the north; N15W to N20E, which dip vertically to steeply to the west. In any one area there is usually only one set of ore-bearing fissures. The part of the district which contains the N70E fissure of the Rebel mine also contains the numerous fissures of the Harrington-Hickory mine area and the White Rock mine area (which adjoins the Harrington-Hickory area on the southwest). The Little May Lilly mine, located about 400 yards southwest of the main adit of the Rebel mine, is also probably located on a fissure.

Faults

It was possible to extend the larger of the two faults crossing the Rebel fissure into the Harrington-Hickory area to the south. Townsend (1953, p4) describes three prominent faults underground in the Harrington-Hickory mine. Two of the faults trend about N80W and one, the East fault, trends about N45W and dips to the west 80 degrees. The East fault can be projected to the surface where it lines up well with the large fault of the Rebel mine area. Unfortunately the surface exposures of the limestone where the fault probably crosses are very poor and the exact trace of the fault could not be located. Concerning the relative age of the faults, Townsend concludes that they are post-mineral, but that "that fact and the displacements have not been determined definitely" (p4).

STRUCTURAL PROBLEMS IN THE REBEL MINE AREA

Two interesting and challenging problems are evident in the Rebel mine area. The first has to do with the previously mentioned (p. 18) sequence of rocks along the west edge of the study area. This sequence abuts discordantly against the tightly folded Rebel limestone. In addition, at (600S, 1200W) (pl. 1) a large mass of highly resistant silicified quartzite breccia is exposed (see fig. 20). The rock is light tan on weathered surface, pure white on fresh surface, and is composed entirely of very angular quartzite blocks and ships silicified into a solid mass 110 feet by 260 feet. Thus we have the situation of a limestone and varicolored quartzite sequence striking into a massive quartzite breccia with uniform limestone of the Rebel limestone on the other side. From the field relations, the most obvious explanation is that a major fault separates the Rebel limestone from the sedimentary sequence to the west, and that the quartzite breccia represents the breccia zone of the fault. The fault appears to dip gently to the west, and as such could be a thrust fault. However, this (thrust?) fault hypothesis does not readily explain the localized nature of the quartzite breccia or the fact that the contact zone between the ribbed limestone and the tightly folded Rebel limestone at (900S, 1000W) (pl. 1) must be very small or nonexistant, as there was no visible evidence of deformation in the ribbed limestone.

The second problem concerns the radical "thickening and thinning" of the "unnamed" quartzite unit. As previously mentioned, the change in thickness is believed to be too great to be solely the result of sedimentary processes. The writer found no field evidence to suggest a possible explanation, but it seems likely that faulting is responsible.

MINERALOGY

The mineralogy of the Rebel mine area is unusually complex for such a small area. In addition to a good variety of typical metamorphic, igneous, and ore minerals, several unusual minerals were noted in small amounts. Many of the minerals are commonplace in their occurrence and development and are discussed only briefly. Others are somewhat unusual in some manner or another and are discussed in more detail.

SULFIDES

Galena - PbS, isometric, the principal ore mineral of the Rebel mine. Understandably, most of the galena originally in the accessible part of the fissure has been mined, but stringers up to one inch across can be found rather easily in the limestone wallrock of the fissure. Galena is also common on the dumps surrounding the fissure. The galena usually occurs as the unoxidized centers of very drab looking, heavy, brown to black nodules.

Chalcopyrite - $CuFeS_2$, tetragonal. One small specimen of "copper pyrite" was found in place in a small prospect at (ON, 200W) (pl. 1).

Pyrite - FeS_2, isometric. Pyrite occurs as a minor constituent of the ores of the Rebel fissure. The crystals are almost always microscopic and are often partially or completely altered to limonite. Thin crusts of pyrite were also observed on several pieces of the arkosic sandstone collected from near the midpoint of the adit at (250N, 50W) (pl. 1).

OXIDES

Specular Hematite - Fe_2O_3, trigonal. Large crystals (to one inch across) of this bright metallic-gray form of hematite occur in many places around the larger phacolith in contact metamorphic skarn rocks. The best localities for specimens are at (300N, 400W) (pl. 1) and (150S, 800W) (pl. 1).

Magnetite - $Fe^{+2}Fe_2^{+3}O_4$, isometric. Magnetite is abundant as one-half to one inch layers separated by calcite and as larger masses in the three deep prospect pits in the vicinity of (700S, 1100W) (pl. 1). Magnetite also occurs as disseminated grains in the igneous rocks and in some of the hornfels.

Limonite. Brown earthy limonite, probably consisting of several hydrous iron oxides, is common on the dumps of the Rebel mine. Most of it was probably derived from pyrite.

Manganese oxides. Manganese oxides are common on the dumps of the Rebel mine, associated with limonite.

CARBONATES

Calcite - $CaCO_3$, trigonal. Calcite occurs in the contact metamorphic rocks and in the Rebel ore bodies, and is the major constituent of the limestones. In the metamorphic rocks, particularly at (300N, 400W) (pl. 1) and in the vicinity of (150S, 800W) (pl. 1), the calcite is very coarse. Cleavage fragments up to three inches across are obtainable.

The calcite which occurs with the fissure ore bodies of the Rebel mine ranges in color from white to dark brown. The dark color is presumably due to very finely disseminated iron and manganese oxides between the calcite grains, as the brown carbonate gives a good calcite (not siderite) x-ray diffraction pattern. The limestones are of course predominantly calcite, but they may once have been partially or wholly dolomitic.

Cerussite - $PbCO_3$, orthorhombic. Cerussite was important as a principal constituent of the ores of the Rebel mine. It is common on the dumps as heavy, brown to black nodules, often inclosing galena.

Malachite - $Cu_2(CO_3)(OH)_2$, monoclinic. Malachite is found as aggregates of microscopic green crystals in cracks of contact metamorphic skarn rocks (see fig. 7). Perhaps the best occurrence is in a small prospect pit at (250N, 150W) (pl. 1).

Azurite - $Cu_3(CO_3)_2(OH)_2$, monoclinic. Azurite occurs as disseminated grains in skarns which are rich in calcite. It is not as common as malachite.

SILICATES

Quartz - SiO_2, hexagonal. Quartz is one of the common minerals in the area. It is the essential mineral in the sandstone, siltstone, and quartzite beds, and it is important in the igneous rocks. Quartz also occurs as a late hydrothermal stage mineral in the contact metamorphic rocks, especially in the immediate vicinity of the scheelite prospect at (900S, 500W) (pl. 1). Attractive groups of small quartz crystals in elongate vugs or "watercourses" can be found on the dump and also as float in the vicinity of (300S, 100W) (pl. 1). A small amount of quartz in very small crystals is also associated with the main fissure deposits of the Rebel mine.

Chalcedony - SiO_2, cryptocrystalline. This form of quartz was noted in small quantities on the dumps of the Rebel mine and prospects, and on the dump of the scheelite prospect. It occurs as banded crusts.

Orthoclase - $KAlSi_3O_8$, monoclinic. Orthoclase is present in the igneous rocks as resorbed, brownish, euhedral phenocrysts up to two cm long and also as anhedral grains in the groundmass. Orthoclase also occurs in the thin arkosic siltstone beds north of the major phacolith.

Adularia - $KAlSi_3O_8$, monoclinic. The variety of orthoclase which occurs in hydrothermal veins as more or less tabular, euhedral or subhedral crystals is called adularia. This mineral was observed in a skarn specimen from (150S, 1150W) (pl. 1), associated with vein quartz and calcite, pale green actinolite needles, small dark green columnar epidote crystals, and andradite and grossularite garnet (fig. 11). The adularia appears to be a late-stage, low-temperature mineral, as it is closely associated with hydroxyl-bearing epidote and actinolite. The crystals of adularia are pearly white and are generally from one to eight mm long.

Plagioclase - $(Na,Ca)Al_{1-2}Si_{3-2}O_8$, triclinic. Plagioclase is an important constituent of the igneous rocks, and, like the orthoclase, occurs as phenocrysts and in the groundmass. The phenocrysts are white and are up to 1.5 cm long.

Kaolinite - $Al_4Si_4O_{10}(OH)_8$, triclinic. Kaolinite is present as a minor alteration product of orthoclase in the igneous rocks.

Serpentine - $Mg_6Si_4O_{10}(OH)_8$, monoclinic. Serpentine occurs as yellow-green translucent masses on recrystallized limestone in and around the Rebel fissure surface stopes and on the dump of the scheelite prospect at (900S, 500W) (pl. 1). The mineral is presumably a product of the dedolomitization of the limestone.

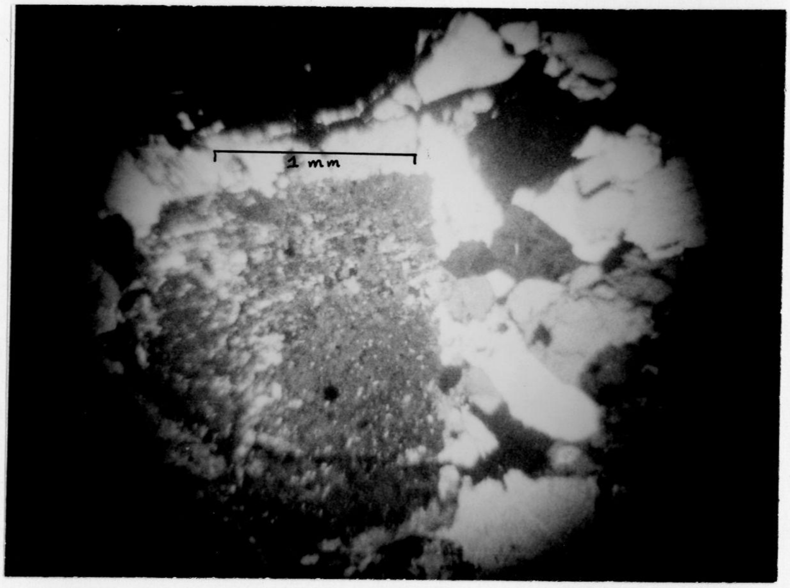

Fig. 11.- Photomicrograph of adularia and other minerals in skarn from (150S, 1150W) (pl. 1).

<u>Talc</u> - $Mg_3Si_4O_{10}(OH)_2$, monoclinic. Talc was determined by x-ray diffraction to be a very minor constituent of the calcite fault gouge present in a number of places in the Rebel mine.

<u>Muscovite</u> - $KAl_2(AlSi_3O_{10})(OH)_2$, monoclinic. Muscovite occurs as masses of transparent, vitreous, watery olive-green crystal plates averaging about 0.5 cm in diameter. The plates have a random orientation and the spaces between the plates are occupied by a dense white powder. The powder was determined by x-ray diffraction to be a submicroscopic mixture of muscovite, calcite, and an amphibole related to tremolite. These muscovite-rich masses are common on the scheelite prospect dump and are very eye-catching in the sunlight. The rock was formed from hydrothermal solutions.

A fine-grained variety of muscovite, *sericite*, is a minor constituent of the hornfels and a minor alteration product of plagioclase in the igneous rocks.

Biotite - $K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$, monoclinic. Biotite occurs as an accessory mineral in the igneous rocks.

Chlorite - $(Mg,Fe,Al)_6(Al,Si)_4O_{10}(OH)_2$, monoclinic. Several of the chlorite minerals occur as alteration products of biotite, garnet, and other minerals in the igneous and metamorphic rocks of the area.

Tremolite - Actinolite - $Ca_2(Mg,Fe)_5(Si_4O_{11})_2(OH)_2$, monoclinic. The amphibole mineral series tremolite-actinolite is moderately common in the metasomatic metamorphic rocks surrounding the intrusions. The series formed under relatively low temperatures; because of this, the two minerals are found in a crude outer zone surrounding the higher temperature minerals garnet and diopside which are formed adjacent to the igneous rocks. Tremolite is white or pale green in hand specimen and non-pleochroic in thin section. Actinolite is medium to dark green and is distinctly pleochroic in thin section. Both minerals occur as radiating needles.

Hornblende - $NaCa_2(Mg,Fe,Al)_5((Si,Al)_4O_{11})_2(OH)_2$, monoclinic. Small, black, lath-shaped crystals of hornblende occur as a lesser constituent of the igneous rocks.

Augite - $Ca(Mg,Fe,Al)(Al,Si)_2O_6$, monoclinic. A few crystals of augite were observed in thin section, partially replaced by hornblende.

The augite is colorless in thin section. The mineral is optically (+), with a 2V of 66°±. $Z \wedge c = -48°$.

Diopside - $CaMgSi_2O_6$, monoclinic. Diopside is very abundant in the metasomatic metamorphic rocks of the area as small (under one mm) anhedral to euhedral crystals primarily associated with garnet.

The diopside, like the augite, is colorless in thin section. It is distinguished from augite on the basis of its optical properties. The diopside is optically (+) with a 2V of 56°. Z c = -37°.

Wollastonite - $CaSiO_3$, triclinic. Wollastonite was observed in only one thin section, where it constituted 99 per cent of the specimen (fig. 12). The hand specimen was collected from the working face of the adit at (250N, 50W) (pl. 1). Close inspection of the hard, white, massive hand specimen reveals myriad glistening needles of wollastonite.

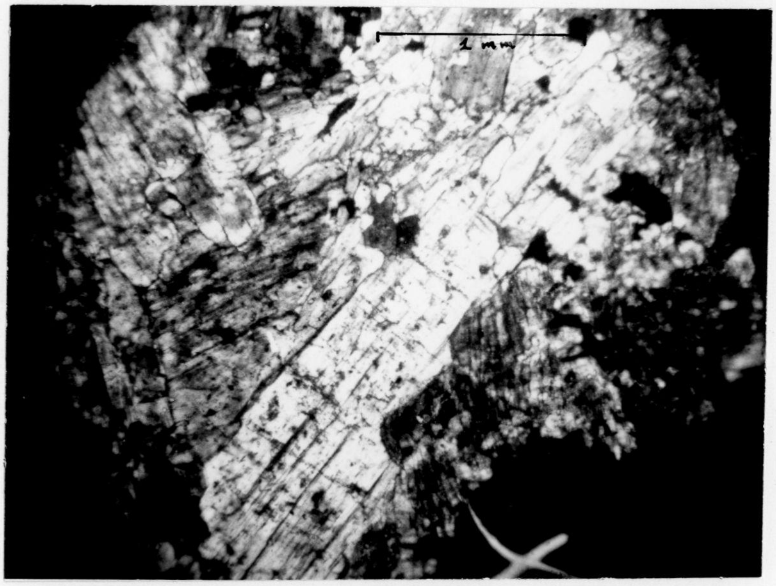

Fig. 12.- Photomicrograph of wollastonite skarn from the adit at (250N, 50W) (pl. 1).

Tourmaline - $Na(Mg,Fe)_3Al_6(BO_3)_3(Si_6O_{18})(OH)_4$, trigonal. Tourmaline is present as an accessory mineral in the hornfels, constituting up to three per cent of the rock (fig. 13). It occurs as the iron-rich variety schorlite in microscopic euhedral crystals.

The schorlite crystals are pleochroic colorless to dark green. ω = green, ϵ = colorless. The crystals are length-fast, or optically (-).

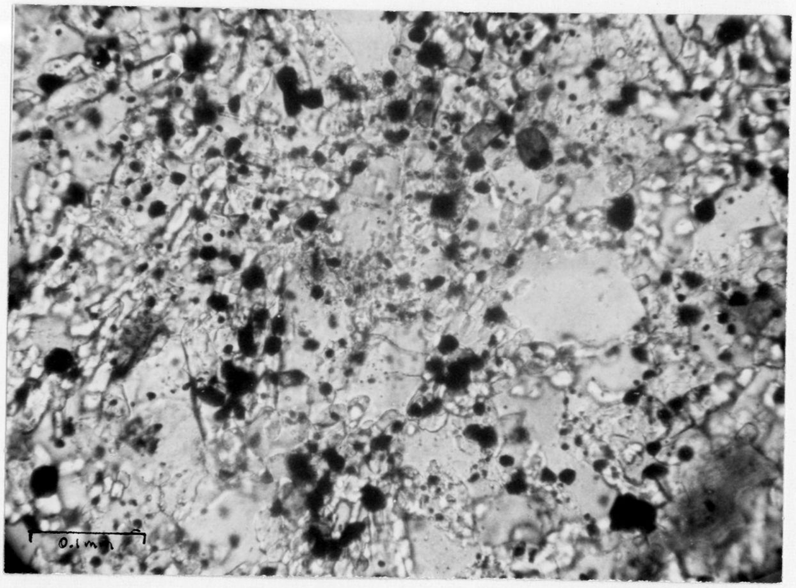

Fig. 13.- Photomicrograph of tourmaline-rich hornfels from (800S, 300W) (pl. 1).

Epidote - $Ca_2(Al,Fe)_3Si_3O_{12}(OH)$, monoclinic. Epidote is common as a minor constituent of the metasomatic metamorphic rocks and as a deuteric alteration product of the igneous rocks. In the metamorphic rocks it occurs as bright yellow-green to dark-green, columnar-striated crystals up to two mm long. In thin section, the mineral is commonly observed in its typical euhedral form. The epidote in the igneous rocks occurs as very small anhedral to euhedral crystals associated with plagioclase and ferromagnesian minerals.

Allanite - $(Ca,re)_2(Al, Fe, Mg)_3Si_3O_{12}(OH)$, monoclinic. The rare earth-bearing epidote, allanite, was sight-identified by Prof. B. F. Stringham of the Department of Mineralogy, University of Utah, in a calcite-tremolite-quartz hornfels from (250N, 400W) (pl. 1) (fig. 14).

Allanite occurs as small subhedral to euhedral crystal grains. The mineral is pleochroic from colorless to deep brown - Z = dark brown, X = colorless. The crystals are commonly twinned on $\{100\}$. The index of the mineral is ca. 1.70, with an estimated birefringence of 0.026. The mineral is optically (-); $2V = 74\text{-}76°$; $X \wedge c = +40°$; $Z \wedge a = +50°$.

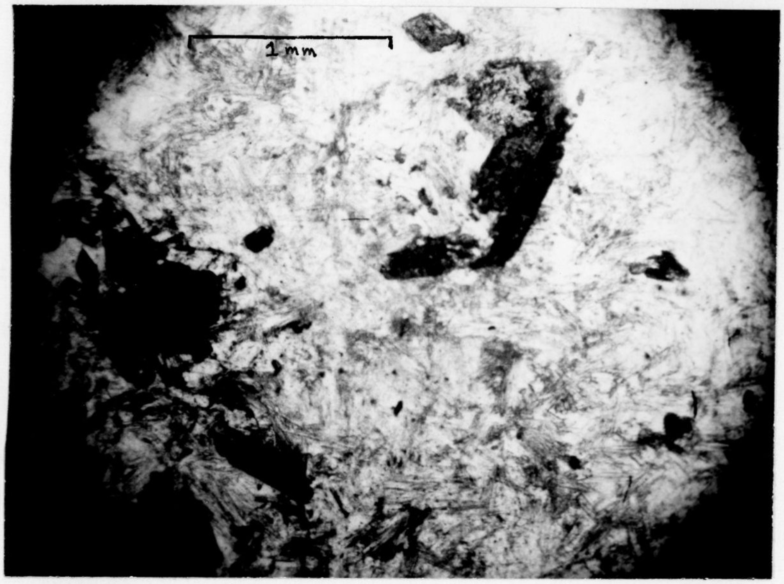

Fig. 14.- Photomicrograph of allanite in hornfels from (250N, 400W) (pl. 1).

<u>Clinohumite</u> (?) - $4Mg_2SiO_4 \cdot Mg(F,OH)_2$, monoclinic. A few rounded grains of a humite group (?) mineral were observed associated with ludwigite and calcite from (800S, 800W) (pl. 1) (see fig. 15). The grains are subhedral and average about 0.3 mm in diameter. General appearance strongly indicates the humite group, and certain properties suggest that the mineral may be somewhere between humite and clinohumite in composition.

The mineral has an index of about 1.64 and a moderate birefringence. The crystals are optically (+) with a 2V of 67°, and are probably monoclinic. One direction of cleavage was observed, with a small angle of extinction to what appears to be the (001) face. No twins were observed.

<u>Grossularite</u> - $Ca_3Al_2(SiO_4)_3$, isometric. Yellow-green grossularite garnet is the most abundant contact metamorphic mineral in the study area.

It occurs massive and in free-growing perfect trapezohedrons and dodecahedrons up to one-half inch across in white calcite. The best location for good crystals is along the southern edge of the larger phacolith.

Andradite - $Ca_3Fe_2(SiO_4)_3$, isometric. The dark brown variety of garnet was observed associated with adularia in a specimen from (150S, 1150W) (pl. 1). Helvite ($Mn_4Be_3Si_3O_{12}S$) was suspected, but the arsenic trisulfide test was negative.

Zircon - $ZrSiO_4$, tetragonal. Zircon is present in the igneous rocks as a very minor accessory mineral.

Sphene - $CaTiSiO_5$, monoclinic. Sphene, like zircon, is a very minor accessory in the igneous rocks.

PHOSPHATES

Apatite - $Ca_5(F,Cl,OH)(PO_4)_3$, hexagonal. Apatite is present in the igneous rocks and metasomatic metamorphic rocks of the area as a minor accessory mineral.

BORATES

Ludwigite - $(Mg,Fe^{+2})Fe^{+3}BO_5$, orthorhombic. The scarce borate ludwigite was found in several large pieces of limestone float at (800S, 800W) (pl. 1). Figures 15 and 16 show the mineral in thin section and in hand specimen. The mineral is present in all gradations from radiating clusters and single needles of dark green crystals to thick black columnar prismatic crystals. The green crystals are almost pure $MgFe^{+3}BO_5$ while the black crystals contain appreciable Fe^{+2}. The optical data obtained for the Mg-rich ludwigite from examination of a thin section and crushed

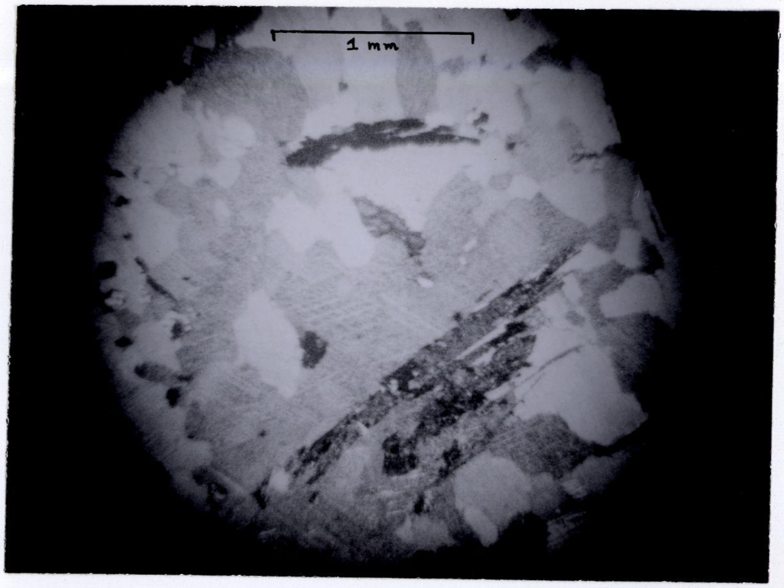

Fig. 15.- Photomicrograph of ludwigite and clinohumite (?) in calcite from (800S, 800W) (pl. 1).

Fig. 16.- Ludwigite in recrystallized limestone (calcite) from (800S, 800W) (pl. 1).

fragments in index oils and melts agrees well with the data obtained by Leonard et. al. (1962).

The Mg-rich ludwigite occurs as pleochroic elongate prisms up to five mm long cutting calcite grains. nZ = 1.95, nY is slightly greater than 1.83, nX is slightly less than 1.83. Birefringence = 0.12. The ludwigite is optically (+) with a small 2V. The crystals are orthorhombic, elongated in the Z vibration direction (length slow). Z=c= medium brown with a tinge of red; Y=b= medium green; X=a= medium green. The tumeric paper spot test for boron showed a positive, although weak, reaction.

SULFATES

Anglesite - $PbSO_4$, orthorhombic. Anglesite occurs intimately with galena as the oxidation product of that sulfide. However, because of the abundance of carbonate and the fact that $PbCO_3$ is much more stable than $PbSO_4$ in a carbonate environment, virtually all of the non-sulfide lead is present as cerussite.

TUNGSTATES AND MOLYBDATES

Scheelite - $Ca(W,Mo)O_4$, tetragonal. Scheelite is abundant in abnormally large crystals on the dump and underground at (900S, 500W) (pl. 1). The average crystals are one-half to one inch across, with occasional individuals up to two inches across. The mineral is white and superficially resembles quartz. Hand-specimen identification is most easily accomplished with the use of a short-wave ultraviolet lamp at night. The mineral fluoresces a brilliant, hard bluish white to yellowish white. Scheelite is closely associated with diopside (see fig. 17). A few small grains of scheelite are also found along the road cut at (250N, 400W) (pl. 1).

A number of large crystals from the scheelite prospect are zoned, with Mo-rich scheelite in the center, and Mo-poor scheelite in the rim.

This was determined by the fluorescence - scheelite rich in molybdenum fluoresces a bright yellow, while pure $CaWO_4$ fluoresces a bright bluish white. The molybdenum end member of the series is powellite, which is isostructural with scheelite.

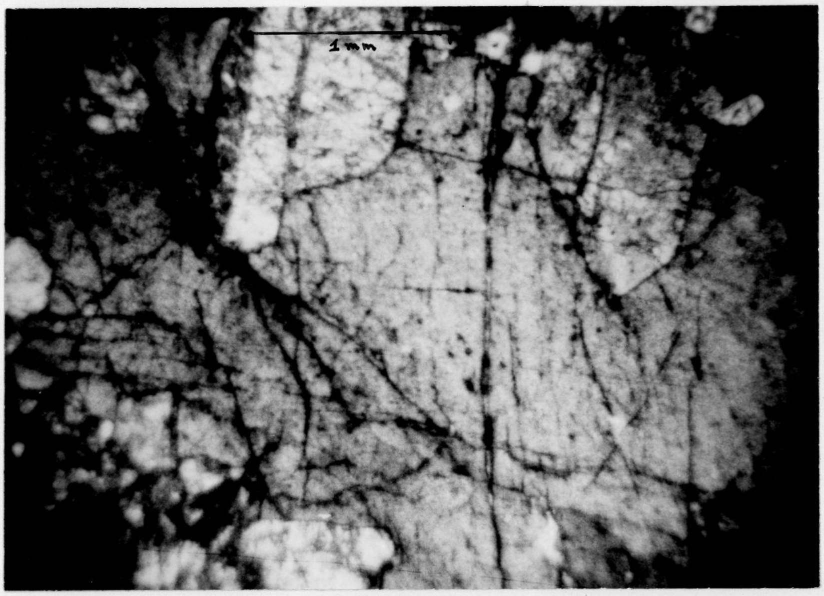

Fig. 17.- Photomicrograph of scheelite embayed by euhedral diopside crystals from the scheelite prospect dump.

Wulfenite - $PbMoO_4$, tetragonal. Wulfenite occurs in a number of places along the main adit and elsewhere in the Rebel mine as small, free-growing, orange to yellow, tabular crystals on calcite fault gouge. The mineral is secondary.

ORE DEPOSITS

GENERAL HISTORY, DEVELOPMENT, AND PRODUCTION OF THE STAR MINING DISTRICT

The Star mining district was organized on July 8, 1870, and subsequently divided into the North Star and the South Star districts on November 11, 1871. The two districts are commonly referred to as the

Star and North Star districts. The dividing line between the districts is Elephant Canyon, thus placing the Rebel mine well within the confines of the North Star district. In practice, the distinction between the districts is seldom made, and the following data and comments apply to the Star district undivided.

Mining activity in the Star district has been spasmotic. The greatest activity in the district occurred in the period from 1871 to 1875. Most of the major mines in the district were located and worked in this early period (Butler, 1913). After 1875 production dropped in the district, and during the 1880's and 90's production was very small. Butler (1913, p118) records an approximate total production for the district from 1870 to 1902 of 1,100,000 dollars. Since 1902, accurate records of mine production have been kept by the U.S. Geol. Survey and the U.S. Bur. of Mines, and these generally have been made available to the public in various publications such as the Minerals Yearbook. The following graph shows the yearly production value for the Star district from 1902 to 1957.

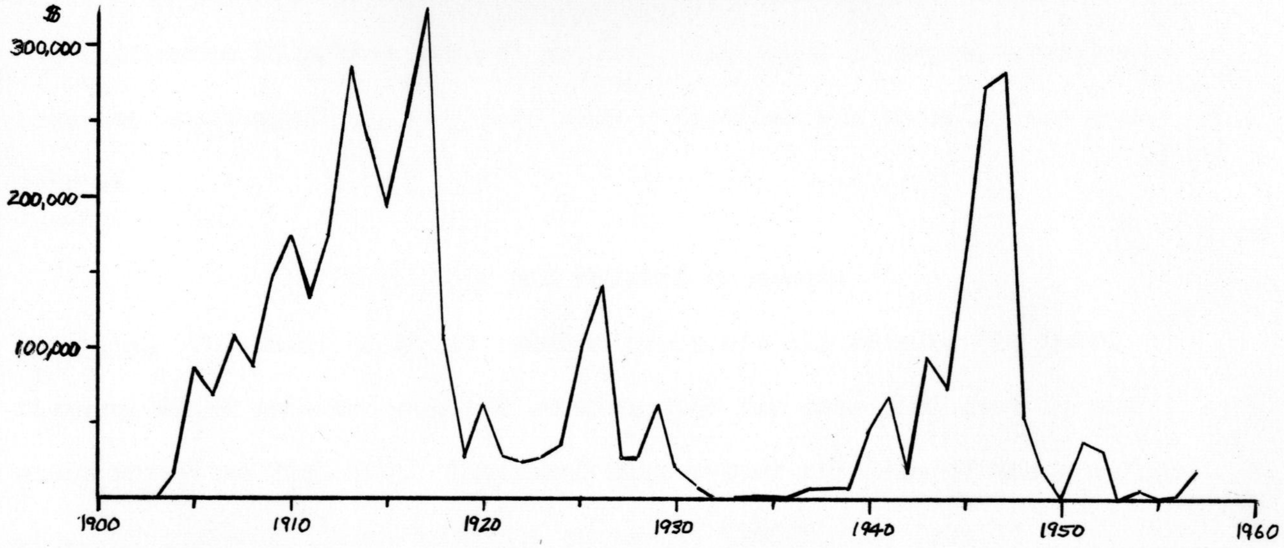

Fig. 18.- Graph showing yearly dollar-value production in the Star district from 1902 to 1957.

As nearly as can be determined, from 1870 to date the district has produced about 5,300,000 dollars in lead, silver, zinc, copper, and gold, in order of decreasing relative value.

The principal mines have been the Harrington-Hickory, Moscow, Red Warrior, Cedar-Talisman, and Mammoth, but some production has come from other mines and a large number of prospects.

Current operations in the district are minor and sporadic.

ORE DEPOSITS AND MINERALIZATION IN THE REBEL MINE AREA

General Statement

The mine and prospects may be divided into those which develop the fissure crossing the study area and those which develop the contact metamorphic zones surrounding the intrusives. The metals present in the fissure are lead, silver, and a little zinc and copper, while the metals present in the contact deposits are tungsten, iron, and copper. Although there has been a small but significant production from the fissure, the production from the contact metamorphic zone probably has been negligible. The difference in metals present in these two types of deposits suggests that the ore-depositing solutions were dissimilar and possibly not even related.

Rebel Mine and Related Prospects

Location. The Rebel mine and related prospects all develop the Rebel fissure, which extends probably continuously for over 3200 feet in the study area (see fig. 10). The Rebel mine proper consists of the workings shown on plate 2. These workings center at (1000S, 0W) (pl. 1).

History, production, and ownership. The Rebel mine was one of the earliest mines in the District. Two claims, Rebel nos. 1 and 2, were located on March 10, 1871,[1] by Joseph Glassford and others. Much legal work ensued during the next two years, with the result that by late 1872 the two claims had been reorganized into one, the Rebel, which was subsequently patented. The Rebel claim covers the important surface workings and the main adit and shaft of the Rebel mine. At probably about the same time, three adjoining claims were patented. These are Twins, Lucky Boy, and Florence. The relative positions of these claims are indicated in figure 19. In the 93 years since the claims were patented, the ownership of the property has become fragmented due to death, tax sale, and other causes. The present ownership of the four claims (as of February 1, 1965) is as follows:

Rebel Lode - Lot 37. 9.19 acres
Twins Lode - U.S. Survey 4454. 16.475 acres
Lucky Boy Lode - U.S. Survey 6302. 13.833 acres
Rough Rider Lode - U.S. Survey 5830. 20.66 acres

B. H. Dwight & Ruel G. Halloran	1/9 undivided	interest
Edward Galloway & Minnie Galloway	1/9 und.	int.
Julia C. Wilkin	1/3 und.	int.
Margaret & Leonard Pilick (Phock?)	1/9 und.	int.
Frederick Pilick (Phock?)	1/9 und.	int.
Frederick Upton Leonard Jr.	1/9 und.	int.
Matthew C. Leonard	1/9 und.	int.
	9/9	

Florence Lode - Lot 57. 20.65 acres

Gilbert A. McCulley	1/2 und.	int.
Jack B. Bardsley	1/2 und.	int.
	2/2	

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[1] The first entry under the Rebel #1 claim in the Beaver County Courthouse records is dated June 10, 1871, but the claim was probably originally located at the same time (i.e. March 10) as the Rebel #2 claim.

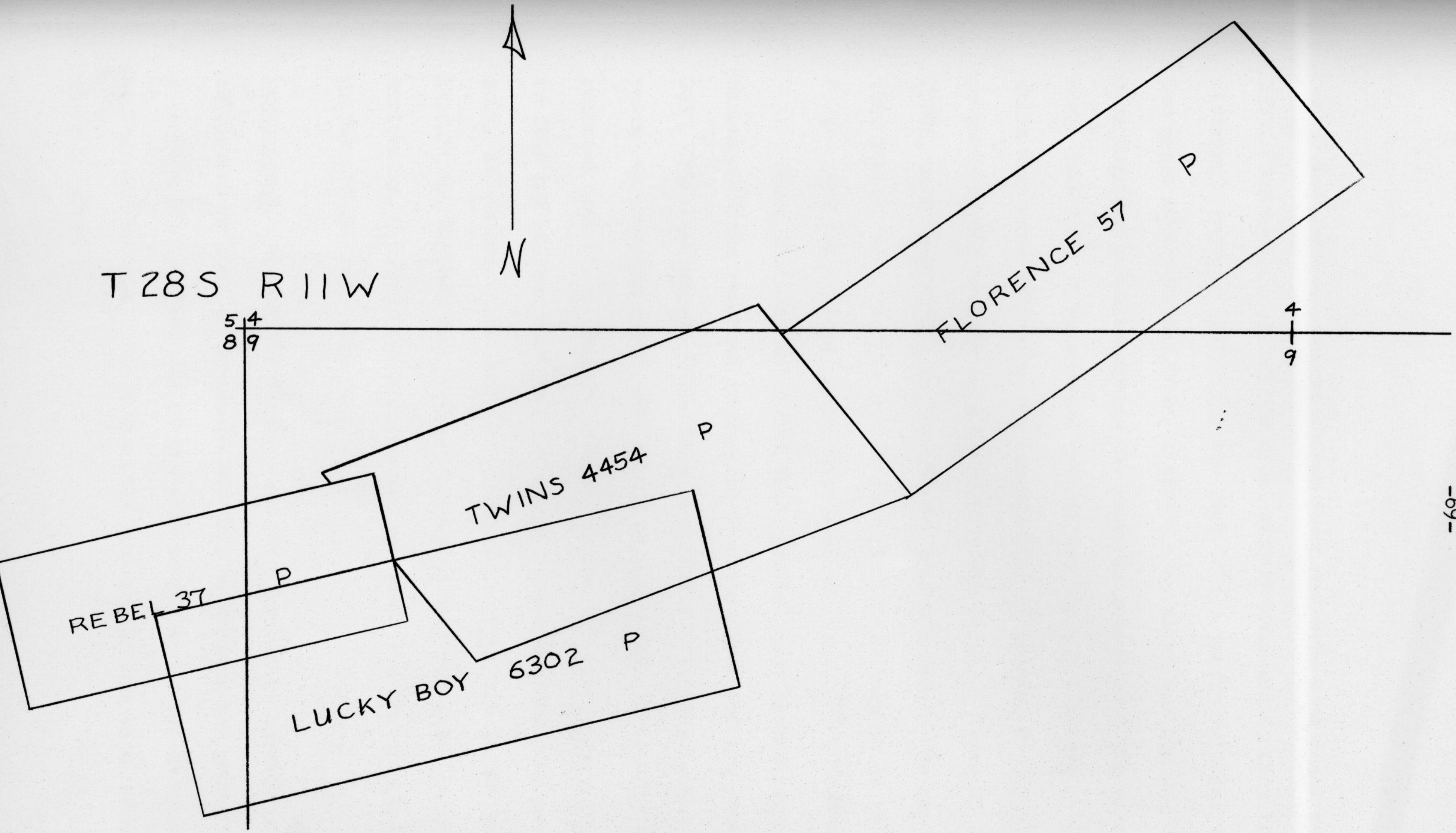


Fig. 19.- Patented claim map of the Rebel mine area (from map by Bureau of Land Management).

Most of the production from the Rebel mine took place from 1872 to 1875. During this period the Rebel was the outstanding mine in the Star district. Raymone (1877 (for the year 1875), pp280-81) states: "The two great mines of the /Star/ district, the Rebel and the Big Bonanza, have together produced during the year, as nearly as I can ascertain, about 3200 tons of galena and carbonates. In the workings of the former, which are quite extensive, an immense body of mineral is exposed, and the property is universally held to be of great value." However, Huntley (1885, p472) reported that by 1880 the mine was idle. The ore mined in this period, according to Huntley, assayed an average of 35 oz silver and 65 per cent lead. Total production was 4000 tons.

Since 1880 the Rebel has been operated only sporadically. The Bureau of Mines reported production from the Rebel for the years 1912, 1917, 1918 (probably), 1946, 1948, and 1949. Total production for these years was probably under 1000 tons. Minerals Yearbook for 1949 (p1584) reported that "J. C. Hanley, lessee, worked the Rebel mine for one month in 1949 and shipped 65 tons of lead smelting ore containing one ounce of gold, 327 ounces of silver, 104 pounds of copper, and 15,625 pounds of lead." Mr. Hanley, who presently lives in Milford, said (personal communication, 2/1/65) that the ore was produced from the dump and also from drifts off the main adit level.

Development. Accessible workings on the four claims consist of a long adit, various smaller crosscuts and drifts, surface and underground stopes, a caved shaft 100 feet SSW of the adit mouth, and numerous prospect pits, shafts, and an adit. The accessible workings of the Rebel mine proper are shown in plate 2.

Many of the workings are now inaccessible. Raymond in his report for 1873 states (table, p282) that ". . . a shaft was sunk 84', with 75' of drifts on the Rebel Claim. The width of the ore body was 4', and 300 tons of ore were extracted." The shaft referred to is probably the caved shaft south of the adit mouth (see pl. 2). This shaft extends much deeper than 84 feet, as indicated by the large barren dump aproned below the shaft mouth and by the reports of several people. Butler (1913, p196) mentioned that in 1909 ". . . a shaft had been sunk to a depth of 200 feet and considerable exploration done on that level, though no commercial ore body had been opened." Mr. Hanley stated (personal communication, 2/1/65) that the shaft extends to a depth of 800 feet, but that he has never been down it. A partially boarded-over inclined winze is located in the adit, 210 feet from the mouth. This winze could not be explored, but it may connect with another level. Also, several of the deep prospect shafts along the fissure may have concealed drifts and crosscuts. None of the prospect shafts along the fissure could be explored because of a lack of time.

The accessible workings, totaling some 600 feet of openings, are in reasonably good condition. The "back" in the adit, drifts, and stopes is standing rather well with little spalling except in places along the adit. With the exception of a few stulls in the stopes, the mine is untimbered.

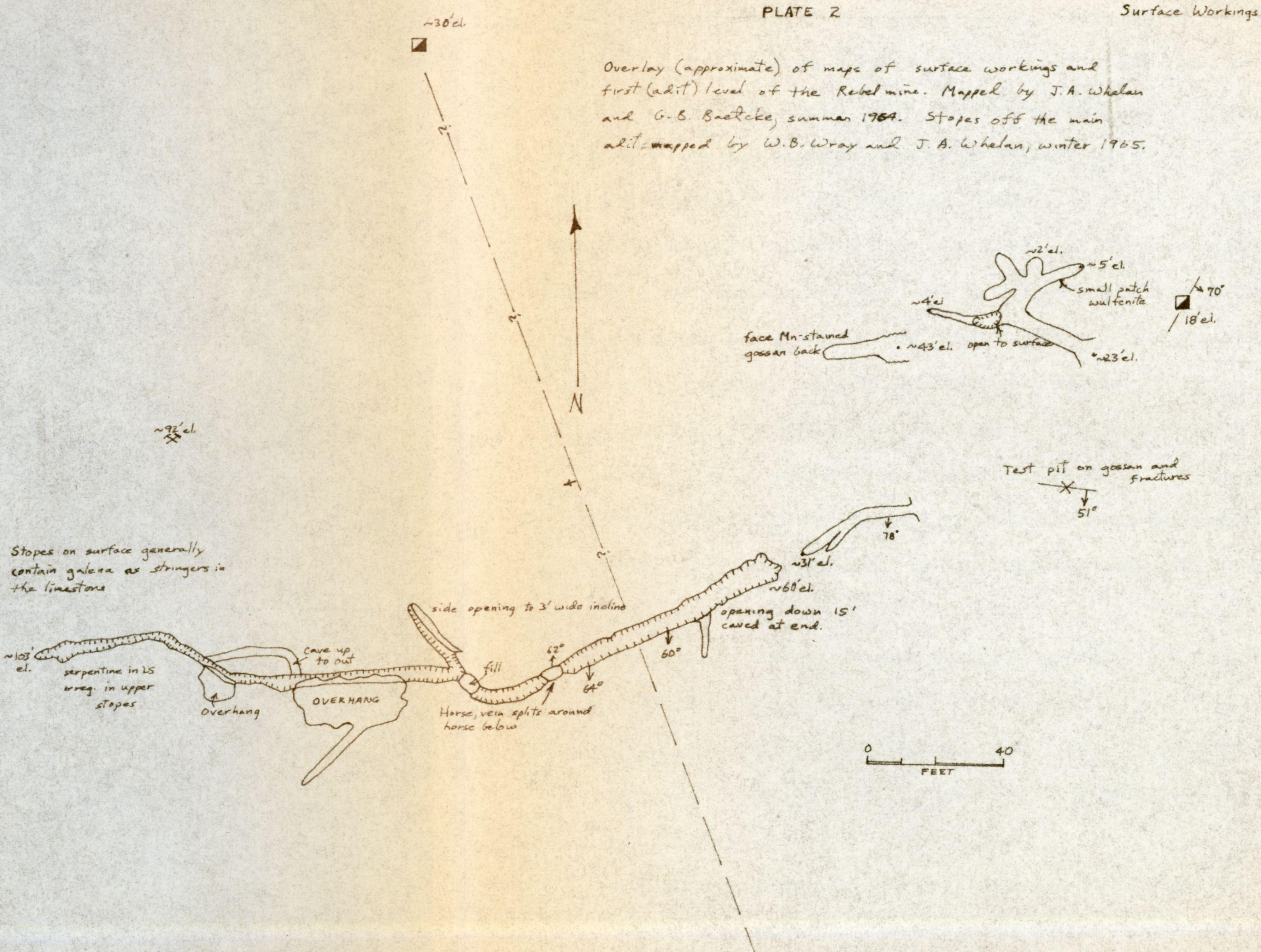
The main shaft is in bad condition. The collar is caved.

Along the fissure there are 11 prospect pits (one west of the mapped area), 11 prospect shafts, some quite deep with large dumps, and one adit, which opens west of the main Rebel workings on the other side

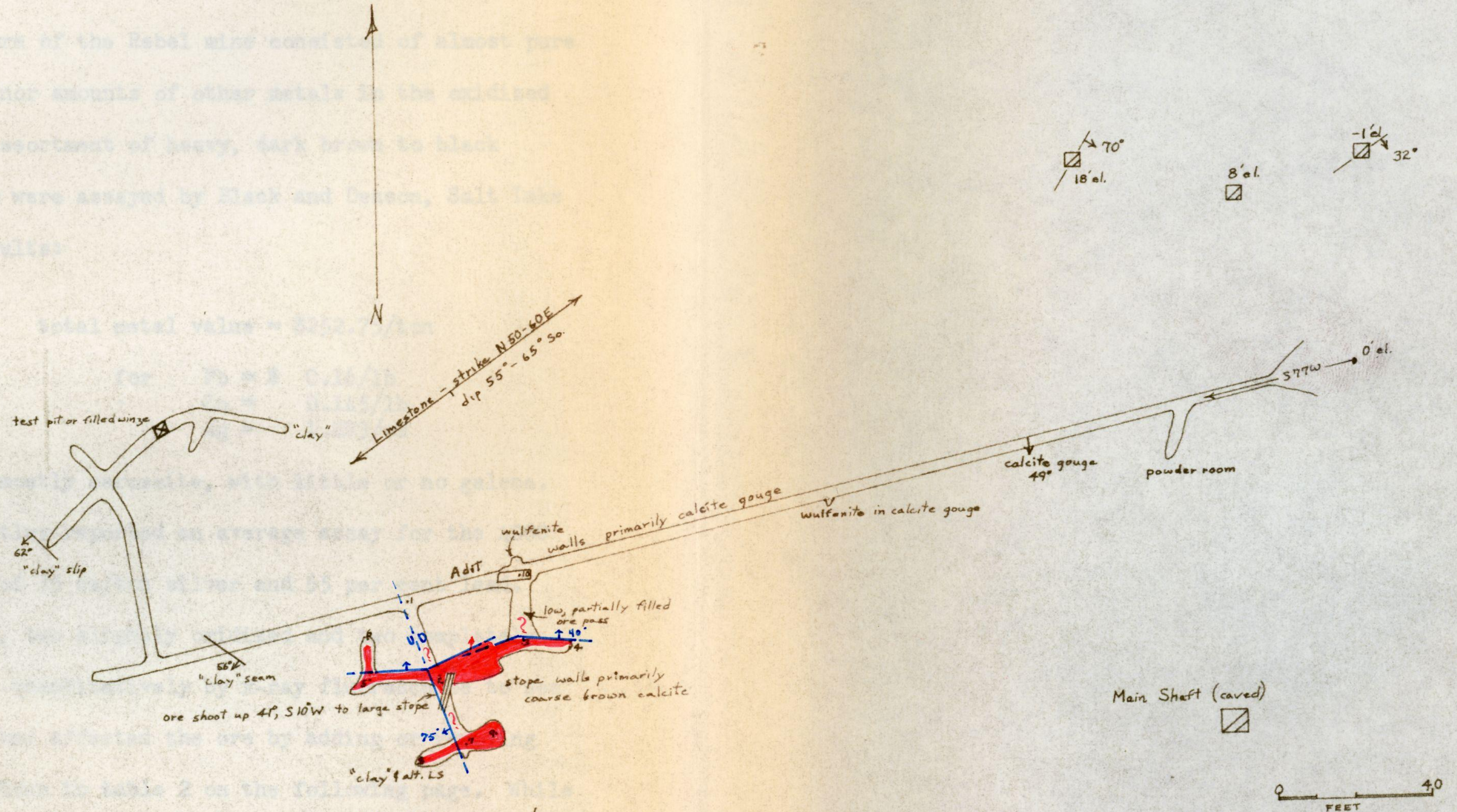
PLATE 2

Surface Workings

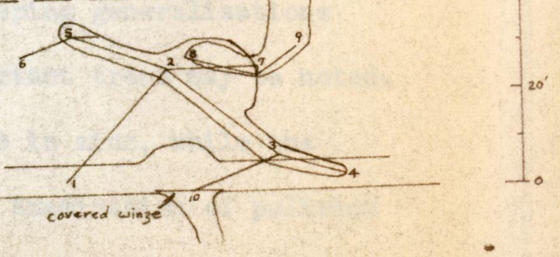
Overlay (approximate) of maps of surface workings and first (adit) level of the Rebel mine. Mapped by J. A. Whelan and G. B. Baetcke, summer 1964. Stopes off the main adit, mapped by W. B. Wray and J. A. Whelan, winter 1965.



First (Adit) Level



Stope and Adit Profiles



of the hill at (1150S, 500W) (pl. 1). There are also one prospect pit and two shafts on the north-trending fault south of the Rebel fissure, and two minor pits east of these shafts on the ridge across the wash. The adit and the two shafts (which join at depth) are mapped as plates 3A and 3B.

Character of the ore. The ore of the Rebel mine consisted of almost pure galena and cerussite with minor amounts of other metals in the oxidized and unoxidized states. An assortment of heavy, dark brown to black chunks collected on the dump were assayed by Black and Deason, Salt Lake City, with the following results:

Au - trace
Ag - 44.4 oz
Pb - 58.0 %
Zn - 6.8 %
Fe - 5.2 %
As - 0.25%

total metal value = $252.75/ton

for Pb = $ 0.16/lb
Zn = 0.145/lb
Ag = 1.293/oz

The fragments were probably mostly cerussite, with little or no galena. As previously mentioned, Huntley reported an average assay for the 4000 tons produced prior to 1880 of 35 oz/ton silver and 65 per cent lead.

Four specimens of ore, two slightly oxidized and two completely oxidized, were analysed semi-quantitatively by x-ray fluorescence to see if the process of oxidation had affected the ore by adding or removing elements. The results are shown in table 2 on the following page. While the limited number of samples tested precludes sweeping generalizations about the migration of elements, at least one important trend may be noted. The completely oxidized samples are relatively high in zinc, while the slightly oxidized samples are much lower in zinc. Examination of polished sections of the ore shows no relict sphalerite or other evidence indicating that primary zinc minerals once occurred with the galena. This indicates that the zinc was carried down from above by solutions, and that the eroded upper portion of the Rebel fissure was relatively rich in zinc.

Table 2.- Comparison of the elements in slightly oxidized and completely oxidized fragments of ore, Rebel mine. Elements are listed in decreasing order of $K\alpha$ x-ray line intensity.

slightly oxidized		completely oxidized	
#2	#4	#1	#3
Pb	Pb	Pb	Pb
Fe	Fe	Fe	Fe-Zn
Cu	Cu	Zn	
Zn	Sr	Cu	Cu
Mn	Zn	Sb	Mn
Sr-Co	Co	Mo	Sr
	Mo	Mn	Ag
Mo	Ag	(Hg?)	Mo
Ag			

Six polished sections of ore were examined. The minerals observed were galena, cerussite, anglesite, pyrite, hematite, and limonite. The copper and zinc minerals which should be present could not be identified. The zinc minerals are probably entirely secondary. The copper mineral is probably chalcopyrite. The silver probably is present in the galena as silver sulfide in solid solution with the lead sulfide. The molybdenum may be contained in the galena forming "molybdiferous galena" as suggested by Butler (1913, p195) for the similar ores of the Harrington-Hickory mine.

<u>Origin, paragenesis, and deposition of the ores</u>. From the nature of the deposit, it seems almost certain that the ores are hydrothermal. From observed field relations, the deposition of the ore appears to have been

controlled by three factors, given below in decreasing order of importance.

1) the fissure
2) the pre-mineral faults which intersect the fissure
3) the lithology

Ore is found only along or near the Rebel fissure. The largest amounts of ore are round at the places where the fissure has cut the two pre-mineral faults. The fault with the larger displacement has more ore associated with it. The presence of reactive limestone (rather than unreactive quartzite) at the fault-fissure intersections allowed the ore body to form outside of the fissure boundary.

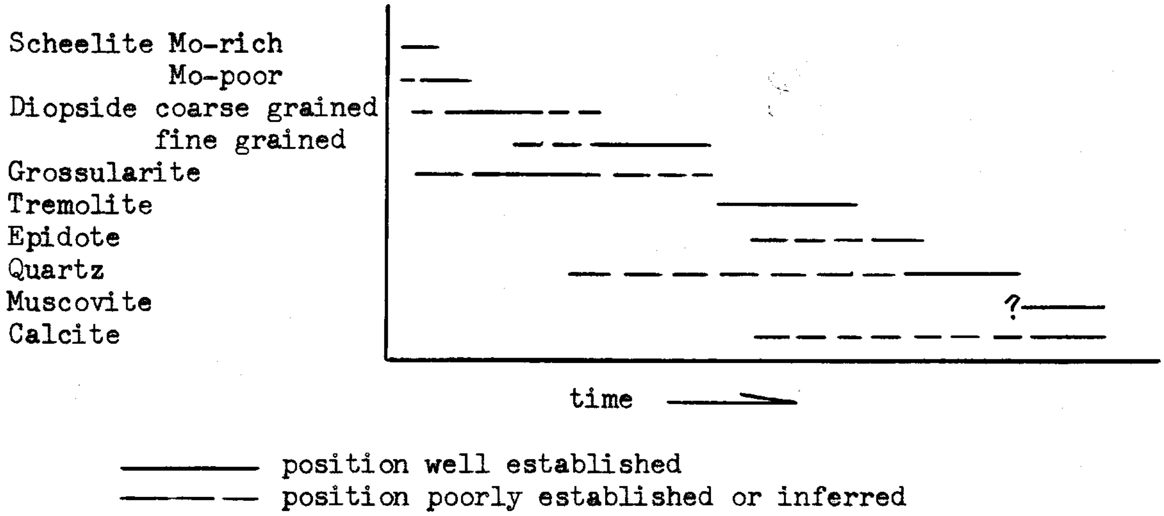
Examination of polished sections of the ore indicates a rather simple and straightforward paragenesis. The first fluids rising along the fissure-fracture zone recrystallized much of the limestone forming white to brown coarse calcite. The galena, pyrite, chalcopyrite (?), and sphalerite (?) formed in the fissure and replaced the calcite and limestone, preferably in the footwalls of both the faults and the fissure. As previously explained, the zinc probably was deposited farther away (i.e. higher) from the source of the mineralizing fluids. Oxidation, probably inhanced by meteoric fluids, formed the secondary lead and zinc minerals which made up an appreciable part of the total ore body.

The ore deposit appears to be mesothermal.

Other Prospects

All of the other prospects in the area are in the metasomatic metamorphic rocks, chiefly the skarns. There are three major prospects plus many small pits. The three prospects are discussed individually on the following pages.

<u>Scheelite prospect</u>. This prospect is located near the bottom of a small gully at (900S, 500W) (pl. 1) (fig. 20). It is developed in a small, isolated skarn zone. Scheelite occurs irregularly in the skarn zone as large, disseminated crystals. The scheelite is associated with typical metasomatic metamorphic minerals. The minerals probably formed in the order given below (see figs, 8, 17).



The prospect consists of about 160 feet of adit in skarn (see map, pl. 3C). Most of the tunnel walls show scattered scheelite crystals, although it appears from examination of the dump that most of the scheelite-rich rock was taken out to the dump. There has probably been no shipment of ore from the prospect.

<u>Magnetite prospect</u> - West of the tungsten prospect lie a group of three shafts, an adit, and several shallow pits which expose several small nearly vertical magnetite veins (fig. 21). Copper carbonate is also common, although not commercial. The adit was started in the stock and remained in igneous rock through its entire length, which indicates that the roof of the stock is very flat and lies close to the surface. It may

Fig. 20.- Scheelite prospect, looking northwest from (1000S, 350W) (pl. 1).

Fig. 21.- Magnetite prospect, looking northwest from (900S, 700W) (pl. 1).

be assumed that the igneous mass lies close to the bottoms of the prospect shafts west of the adit. Plate 3D shows a map of the shafts and the underground workings.

Roadcut prospect - North of the larger phacolith are several small adits and a prospect pit which were apparently exploratory, as no ore was observed (see fig. 2). Some malachite occurs in the prospect pit, and a few small crystals of scheelite occur in the upper roadcut just south of the short adit. The area was apparently of interest chiefly because of the wide variety of metamorphic rocks exposed. Three diamond drill holes were seen in the vicinity of the lower (east) adit, but apparently no significant ore was discovered.

Miscellaneous prospects - A number of small prospects are located around the major phacolith and elsewhere. Most of them explore weak copper showings, and none are of economic importance.

Control of the property - Eugene N. Davie of Milford, Utah, holds a total of 44 contiguous claims in the area north, west, and southwest of the Rebel group of patented claims. His claims include all of the prospects described above. The claims are

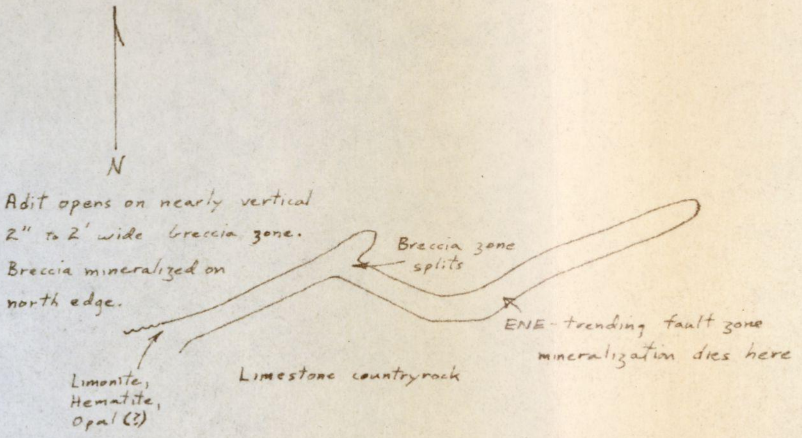
Polaris lode claim nos. 1-36
Polaris Fraction lode claim
Polaris Fraction no. 1 lode claim
Milford Lilly
Milford Lilly nos. 1-4
Milford Lilly Fraction

The Milford Lilly claims were located in 1927 and 1930. Mr. Davie acquired the claims from the Little May Mining Company by purchase in 1961. The Polaris Fraction claims and Polaris lode claims nos. 1-6 were located by Mr. Davie in 1956. The Polaris lode claims nos. 7-36 were located in 1962. Assessment work on the claims is up to date.

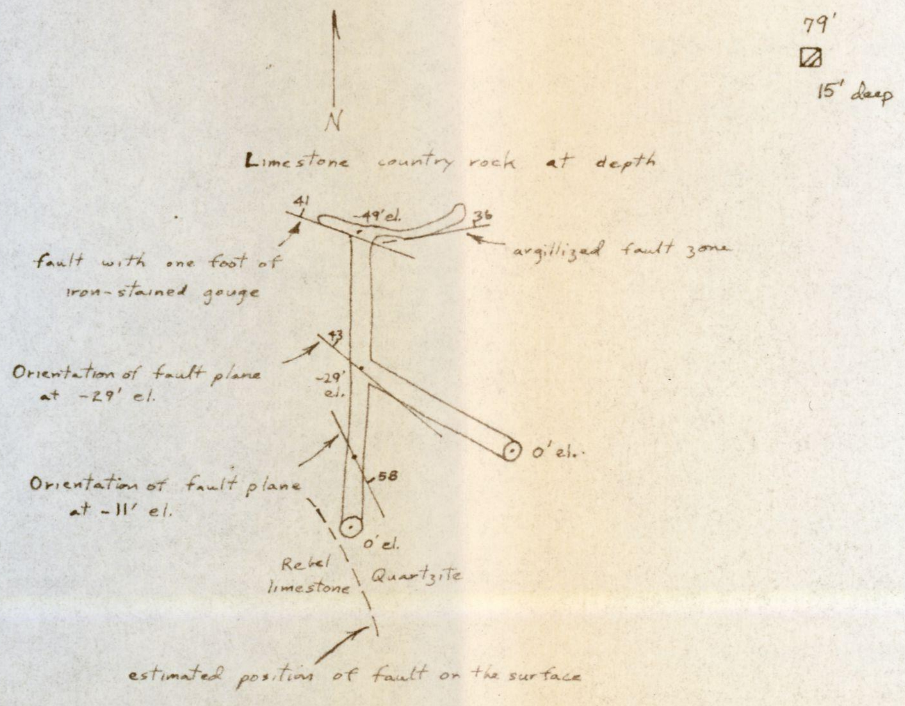
Plate 3 - Prospect Maps

0 40
Feet

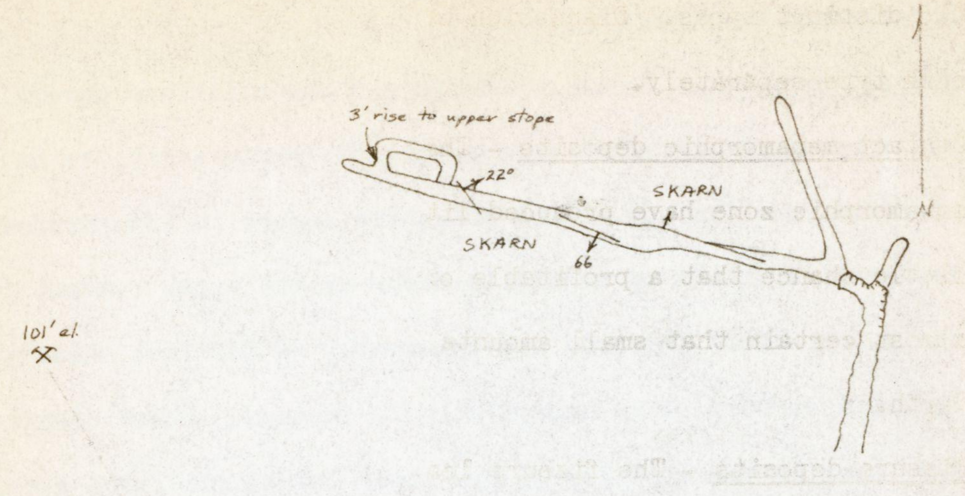
Pl. 3A - Map of the prospect adit on the Rebel fissure west of the Rebel mine



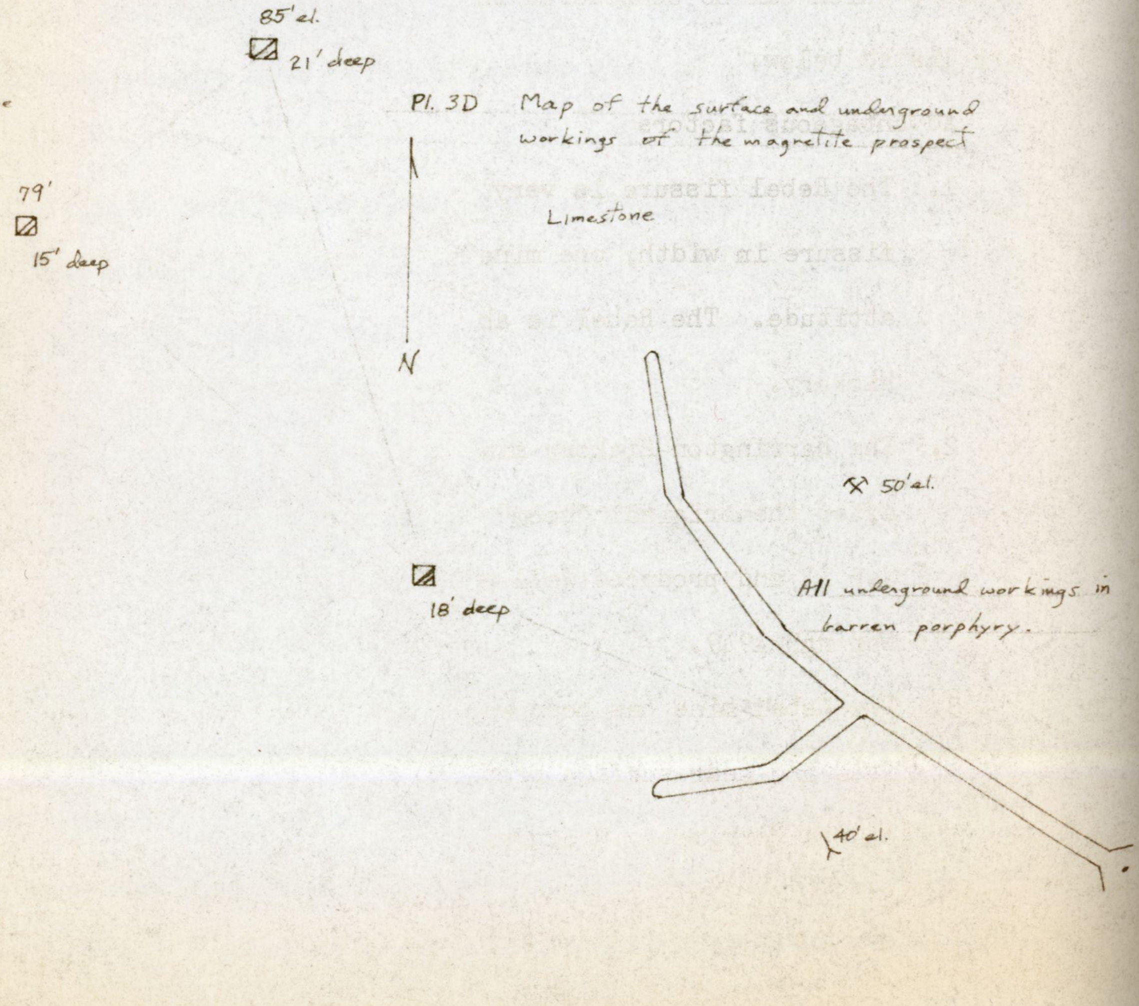
Pl. 3B - Map of the prospect shafts southeast of the Rebel mine



Pl. 3C - Map of the scheelite prospect



Pl. 3D Map of the surface and underground workings of the magnetite prospect



Economic Potential of the Rebel Mine Area

As has been noted, the ore deposits of the Rebel mine area are of two distinct types. Discussion of the potential of the area will cover each type separately.

<u>Contact metamorphic deposits</u> - The prospects which develop the contact metamorphic zone have produced little or no ore. There appears to be little chance that a profitable ore body lies at depth, although it is almost certain that small amounts of economic minerals occur in skarns at depth.

<u>Fissure deposits</u> - The fissure lead-silver-zinc deposits, on the other hand, appear to the writer to be potentially profitable. Some of the factors which can be considered in a qualitative appraisal of the Rebel are listed below.

Advantageous factors

1. The Rebel fissure is very similar to the Harrington-Hickory fissure in width, ore mineralogy, grade of ore, orientation, and attitude. The Rebel is about 600 yards north of the Harrington-Hickory.
2. The Harrington-Hickory mine, which lay inactive for many years after the original "boom" period, was reactivated during World War II and produced well over 500,000 dollars in ore from 1944 through 1949.
3. The Rebel mine has been worked only near the surface. Its surface and near-surface production was apparently greater than that of the Harrington-Hickory.

4. The Harrington-Hickory fissure has been worked to a depth of at least 600 feet. It is very possible that ore may extend to a similar depth in the Rebel fissure. Early reports were glowing in their descriptions of the Rebel (see p), yet by 1880 the mine was essentially dead. Possibly the ore body at depth was offset by a post-mineral fault, or possibly the fissure pinched and the miners abandoned the mine without sinking deeper.
5. If ore <u>is</u> discovered at depth, the Rebel is well situated with respect to Milford and the Railroad. Mining costs in general probably would be low.

Adverse factors

1. The very fact that the Rebel was abandoned at an early date and never revived indicates a lack of ore which, in all fairness, is probably <u>real</u> rather than <u>apparent</u>. However, the writer believes that the Rebel has enough potential to warrant further work.

The following list represents the steps, in order, which the writer feels might prove worthwhile in an evaluation of the potential of the Rebel mine. It must be borne in mind that at no time should cumulative capital expenditures for exploration, development, plant, and property exceed the product of the current "risk factor" (estimated fractional chance for developing a profitable ore body) and the estimated total value of the ore body after subtracting predicted operating (mining and shipping) costs. This "risk factor" of course should be re-evaluated after ever expenditure.

1. Examine carefully the mapped workings of the Rebel mine proper. Determine the exact overlay of the surface and adit level sheets

of plate 2. Readjust geologic interpretations and observations if necessary.

2. Carefully map the upper stopes which were not mapped for plate 2. Investigate the winze (220 feet inside the main adit) and map any workings on lower levels. Map the principal prospect shafts on the fissure east of the Rebel mine proper.
3. If the winze does not connect with the main shaft, repair the main shaft and map the workings off the shaft.
4. a) Diamond drill the fissure, if it is discovered at depth.

<u>or</u>

b) If still feasible after steps 2 and 3, drill a spray of five holes as shown below on this detail from plate 2. If the ore body was localized by the intersection of the fissure and the fault, this spray will probably pick up a continuation of the ore body at depth if it exists. A suggested order of drilling is indicated by the letters A to E.

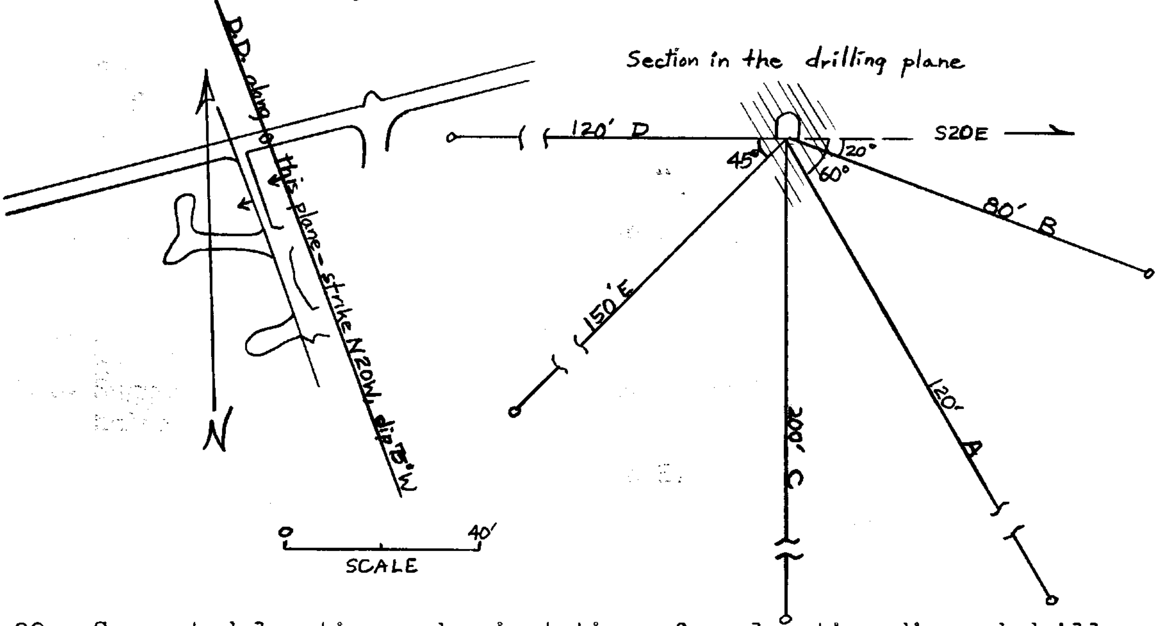


Fig. 22.- Suggested location and orientation of exploration diamond drill holes in the Rebel mine.

c) Drill any promising fissure showings in the prospect shafts at (650S, 800E), (450S, 1300E), or (300S, 1800E) (pl. 1).

APPENDIX

Reconnaissance Analysis of the Rebel Dumps

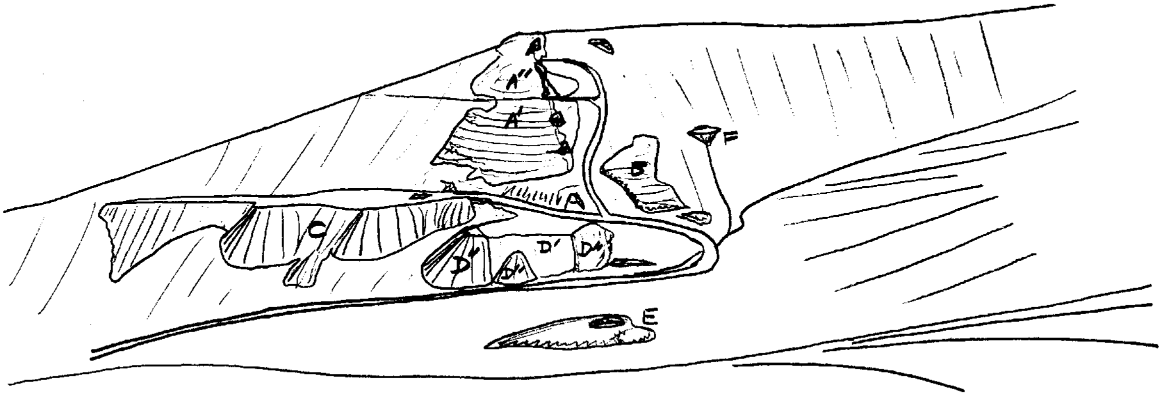


Fig. 23.- Sketch of the Rebel dump system, looking west from (900S, 450E) (pl. 1).

Dump System (fig. 23)

A. Material from the surface stopes in and adjacent to the main fissure.

B. Material from the surface stopes in and adjacent to a small fissure (?) just north of the main fissure.

C. Material from the main shaft.

D. Material from the adit level workings, including connected stopes and winzes, plus material from the prospect shaft alongside the dump.

E. Material from several prospects in the fissure just east of the access road.

F. Material from the prospect shaft north of the fissure.

G. (not shown) Material from the two prospect shafts at (650S, 800E) (pl. 1).

H. (not shown) Material from the prospect shafts at (500S, 1300E) (pl. 1) and (300S, 1800E) (pl. 1).

Analysis of the Dumps

The Rebel dumps were investigated to determine if they contain significant metal values and if the metals can be profitably extracted. Three assays of random shovel samples were made by Black and Deason, Salt Lake City. Each sample consisted of about ten partial shovel-loads of dump material selected from various spots on the particular dump. The samples were crushed and split to a weight of about three pounds and then sent to the assayer. The results are given below.

Metal	A'dump sample	C dump sample	D dump sample (2/3D' + 1/3D")
Au	Trace	Trace	Trace
Ag	4.0 oz	Trace	2.0 oz
Pb	7.4 %	-	7.9 %
Zn	3.0 %	-	2.6 %
Total metal value	$ 37.57/ton	$ 0	$ 35.44/ton

for

Pb = $ 0.16/lb
Zn = 0.145/lb
Ag = 1.293/oz

Unfortunately no rock fragments larger than three inches could be taken in the samples. It seems probable from examination of the dumps that the larger fragments have a somewhat smaller metal content than the smaller fragments. The dumps were examined with the results of the assays in mind. From the general mineralogic appearance of each dump, a value factor was assigned that related the estimated worth of the material to the known (assayed) worth of material of known mineralogic appearance. As an example, if a dump appeared to be eight-tenths as rich as the material from dump A' that was assayed, a value factor of 0.8A' was given the dump. The worth of the dump is then the product of 0.8 and \$ 37.57/ton, or about \$ 30.00/ton. The amount of rock in tons on each dump was roughly calculated using the equation below.

tons of rock = est. volume (cu. yds.) x 0.75 x 0.842 x est. specific gravity of the rock.

where : 0.75 is the breakage factor, allowing for an average 33 per cent increase in volume of the broken rock over the solid rock.

0.842 is the fraction of a ton that one cubic yard of water weighs.

specific gravity is the ratio of the weight of the rock to the weight of an equal volume of water.

The worth of the dump is given by the equation below.

dump value = tons of rock x value factor (explained above)

The individual dumps are discussed briefly below.

Dump A

Dump A appears to be the richest, both in overall grade and in total value. Many fragments of galena and cerussite and a little wulfenite can be seen on the dump. The rocks on the dump vary in size from one-foot boulders to pea-sized granules. The dump consists of a large number of small piles of rock apparently constructed with some order and thought. The piles average perhaps seven feet by seven feet in plan view and are usually separated (in the direction up the hill parallel to the fissure) by clear spaces of several feet, resulting in a terraced effect. The piles are generally either of large <u>or</u> small rock fragments. The depth of the dump is generally less than one yard, but the surface area is very large. Most of the dump lies south of the fissure.

Dump A is differentiated into two parts, designated in the sketch (fig. 23) as A' and A". A' appears to be the richer of the two parts, but this is offset somewhat by the fact that A" has a greater average depth than A' so that less waste rock and dirt will be picked up in the process of mining the dumps.

A' tons of rock = (86x30x0.5) x 0.75 x 0.842 x 3.4 = 2.8 x 10^3 tons
dump value = 2.8 x 10^3 x 0.9A' = ca. $ 95,000

A" tons of rock = (40x10x0.7) x 0.75 x 0.842 x 3.4 = 6.0 x 10^2 tons
dump value = 6.0 x 10^2 x 0.8A' = ca. $ 18,000

The dump can be worked with a D-6 or D-4 size tractor and a skiploader. The tractor can push ore down the hill and into piles where the skiploader can load the rock directly to trucks.

Dump B

Dump B consists mostly of stained limestone with some recrystallized calcite and fragments of ore. The dump is heterogeneous and for the most part unsorted. As the rock came from a series of small exploratory pits and inclines, the metals content of the dump is undoubtably much less than that of dump A. The value factor is perhaps 0.5-0.6A'. No calculations were made on this dump. It can be worked in a similar manner to dump A.

Dump C

Dump C is by far the largest dump; it is also probably worthless.

The dump is composed entirely (on the surface at least) of white limestone. The shovel sample from this dump assayed no value.

Dump D

Part of dump D is potentially the most valuable portion of the Rebel dumps. The dump is divided into two parts, designated D' and D". By far the largest part is D', which appears to consist of the limestone removed from the adit and related crosscuts. This part of the dump probably has a very low value. On the other hand, D" is quite rich in stringers and fragments of galena and cerussite. The rock is all brown recrystallized calcite which most probably came from the stopes at the intersection of the fault and the fissure. Only the value of D" was calculated.

D" tons of rock = (ca. 5) x 0.75 x 0.842 x 3.4 = 1.1×10^2 tons dump

value = $1.1 \times 10^2 \times 1.4$D = ca. $\underline{\$\ 5,600}$

Dump D can be worked with only a skiploader, as the dump is steep-sided and rather high.

Dump E

Dump E consists mainly of stained limestone. The dump is small and contamination with soil and stream debris would be a problem in removing the rock.

Dump F

Dump F is again mostly low-grade stained limestone. The dump is too small to warrant any work.

Dumps G and H

Both of these dumps are very similar in size and mineralogy. The rock is mostly sheeted limestone which is heavily mineralized with iron, manganese, and some galena and cerussite. Virtually all of the dump rock appears to have come from the fissure proper. No assays were made on rock from these dumps, but it seems probable that the rock contains appreciable lead and silver. Both dumps warrant further investigation.

Conclusions - Dump A and part D" of dump D show a total worth of about 119,000 dollars in about 3500 tons of rock, or about $ 34.00/ton in lead, silver, and zinc. However, it is not possible at the present time to market the dumps at a profit. Inquiry at the Tooele custom smelter, operated by International Smelting and Refining Company, indicates that the grade of the dumps is not sufficient to pay for smelter costs. However, if the dumps could be concentrated cheaply, perferably by an operation at or near the mine, then the resultant high-grade material could be shipped to Tooele profitably.

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