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UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STRATEGIC MINERALS INVESTIGATIONS
PRELIMINARY MAPS 3-180

GEOLOGY OF THE SAN MANUEL AREA, PINAL COUNTY, ARIZONA

By G. M. Schwartz
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The San Manuel area in the Old Hat mining district, Pinal County, Ariz., is about a mile south of Tiger, town site of the Mammoth-St. Anthony mine, well-known producer of gold, molybdenum, vanadium, lead, and zinc. Recent exploration has indicated a large low-grade copper deposit in the San Manuel area. If present indications of size and grade are substantiated and if suitable mining and metallurgical methods are developed, this may prove the most important Arizona copper discovery in the last decade.

The San Manuel copper area is named from a group of claims which cover part of the mineralized area. Chrysocolla is relatively abundant at the surface southeast of Red Hill in a small triangular outcrop near the center of the map area (just north of coordinates 0 - 4,000 S, pls. 1 and 2) and at a few places elsewhere. This showing of copper minerals led to shallow prospecting, probably at an early date, but the low grade of the mineralized rock discouraged deep exploration. At one time three drill holes were put down, but the exploration was abandoned and the results are not known.

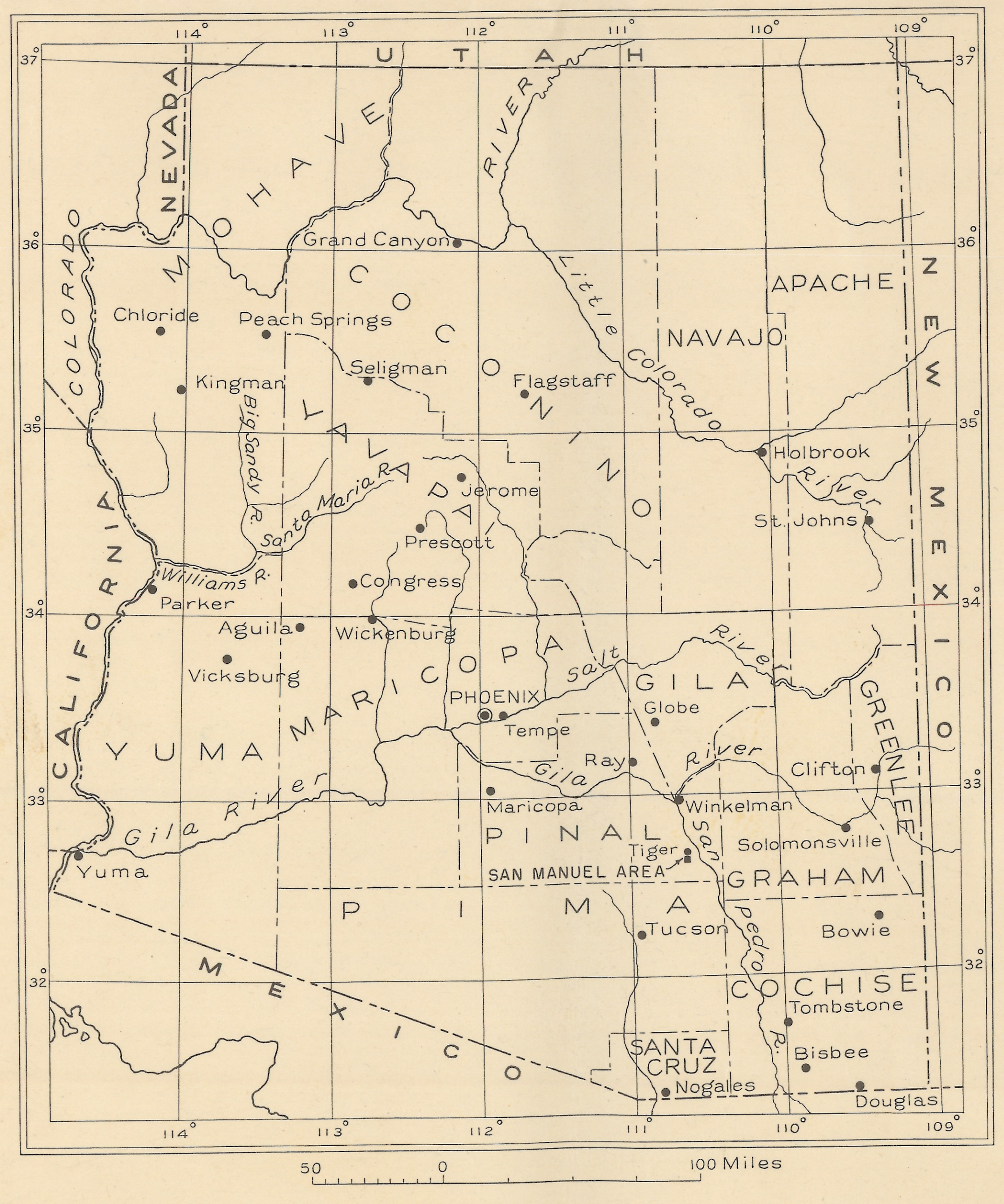
Recent interest in the San Manuel copper showing was stimulated by the possibility of obtaining quick production of copper for the war. In October 1942, a report on the San Manuel group of claims was made to the Reconstruction Finance Corp. by one of the owners, Henry W. Nichols. The War Production Board consequently requested the Geological Survey to appraise the deposit and later requested the Bureau of Mines to test the copper values at depth by drilling. In response to these requests, N. P. Peterson and B. S. Butler of the Geological Survey examined the deposit and submitted recommendations in March 1943; and in October the Bureau of Mines examined the property and selected it for an exploration project. Drilling was begun in November 1943 and terminated in February 1945. Further drilling is being carried on by private companies.

In January 1944, the Geological Survey assigned D. H. Kupfer to make a detailed geologic study of the San Manuel area and to correlate the surface and subsurface information. In July this assignment was taken over by G. M. Schwartz, when Kupfer was called to active duty in the Navy. A brief account of the geology, together with geologic maps and sections of the area, are presented here to make the information available in advance of a more complete report to be issued later. Part of the information on the character, alteration, and mineralization of the rocks has been secured from a study of drill cuttings furnished by the Bureau of Mines and by the Magma Copper Co.

Geology

Rocks.—Relatively few rock formations are exposed in the area. These are, from oldest to youngest, quartz monzonite, monzonite porphyry, diabase, felsite and felsite breccia, Gila conglomerate, and Recent alluvium. The quartz monzonite is believed to be of pre-Cambrian age. The monzonite porphyry, which intrudes it, may well belong to a much later epoch of intrusion, possibly early Tertiary. The beds of Gila conglomerate were probably deposited during Pliocene and Pleistocene time.

The quartz monzonite is part of a mass of granitic rock which occupies a large area on the north slopes of the Santa Catalina Mountains and is commonly known as the Oracle granite. The unaltered rock is a light-pinkish, coarse-grained, porphyritic rock, liberally spotted with black biotite. Fine-grained aplite dikes cut the coarse-grained facies on Red Hill and in some of the drill holes. Over most of the map area the quartz monzonite has been intensely affected by hydrothermal alteration, and locally it has been impregnated with copper minerals.



Monzonite porphyry occurs as irregular intrusions in the quartz monzonite, and has suffered similar alteration and mineralization. The porphyry is much finer grained than the quartz monzonite, and is easily distinguished from it. None of the monzonite porphyry examined to date has escaped partial alteration, but the least altered porphyry contains phenocrysts of oligoclase and biotite in a fine-grained groundmass of orthoclase and quartz.

Diabase dikes occur in the northern part of the map area and along the northwest side of the main mineralized area, about 1,000 feet southeast of Red Hill (pls. 1 and 2). Similar material has been encountered in some of the drill holes. The diabase dikes are clearly later than the monzonite porphyry, which they intrude.

Cutting across the diabase southeast of Red Hill, and therefore of later age, is a compound branching dike of felsite and felsite breccia. The felsite is a very fine-grained light-gray rock with a few small feldspar and quartz phenocrysts, and a finely crystalline groundmass which has a slightly spherulitic texture. The breccia consists mainly of felsite fragments, but quartz monzonite and other rock fragments are also present. The matrix is a light-gray felsitic material. Similar felsite has been encountered in several of the San Manuel drill holes (pl. 4), and intrusive masses of felsite are abundant also in the vicinity of the Mammoth-St. Anthony mine a mile to the north.

The Gila conglomerate covers all other rocks along the south and east sides of the area. It consists of a complex deposit of alluvial material, interbedded with lava flows and volcanic breccias and tuffs. The prevailing rock at the surface in the map area is a coarse conglomerate composed of basic and acidic lava flow pebbles and boulders with a clay cement. Extensive erosion has formed gullies and dry "washes" in the Gila conglomerate and older rocks. All of the larger washes have alluvial deposits left by the floods following heavy rains.

Structure.—The structure of the San Manuel area is fairly complex; it can be only partially interpreted because of the massive character of the older rocks and the tendency of the Gila conglomerate to disintegrate at the surface. The central and northern parts of the area consist mainly of extensive exposures of the quartz monzonite intruded by irregular masses of monzonite porphyry. At places the porphyry and quartz monzonite are so complexly and intimately related that it is impractical to map all of the details. Small dikes of diabase and of felsite also occur in the northern and central parts of the area, and in the area of copper mineralization, southeast of Red Hill, a rather narrow (12 ft.) diabase dike divides the area of heavy pyritic mineralization on the north from the less pyritic copper mineralization to the south (pls. 1 and 2). This dike is rather straight where well exposed, and small outcrops occur to the east along its line of projection. The dip is steep to the south. The form of the dike suggests that it may have been intruded along a fault.

The only bedded rock in the area is the Gila conglomerate, which has been extensively deformed. The prevailing strike is roughly northwest and the dip is predominantly northeast. The dip averages about 35°; it is rarely less than 25° nor greater than 45° in the immediate area, but in adjacent regions, it may be as high as 60°.

Numerous faults that cut the Gila conglomerate are shown on the map, and still others doubtless exist within the area. The principal faults of post-Gila age fall into two sets: an early set of low-angle faults which strike west-northwest and dip southwest, and a set of later steep faults which strike north-northwest and dip northeast.

The steep fault along the east side of the area is probably the southward extension of the Mammoth fault. Another steep fault forms the east side of the main mineralized outcrop. The latter fault is well exposed in a shaft near CDH 9 (pl. 2), where it dips 60° E. Within the map area, the Mammoth fault is poorly exposed except in an exploration pit at the north end, where it dips steeply to the east. The extension of the steeply dipping fault southward from this pit is indicated by the straightness of the Gila contact with the older rocks.

The low-angle faults are exemplified by the important San Manuel fault, which lies along the southwest side of the exposed mineralized area. This fault is presumed to be a normal fault, even though, on the basis of drill logs and exposures in exploration pits, it appears to have an average dip of only about 30°, flattening somewhat to the southwest. The conglomerate beds above the fault dip 30° to 35° E., and if this dip is due to tilting of the region after formation of the San Manuel fault, the fault surface may have originally dipped more steeply.

The low-angle faults of the San Manuel set are believed to be offset by the steep faults of the Mammoth set. The short, low-angle faults in the east-central part of the map area are supposed therefore to be downthrown segments of the San Manuel fault (pl. 4, sec. A-A'). This hypothesis seems to fit information from outcrops and drill holes and permits a logical explanation of the fault relations.

Hypogene alteration and mineralization.—Most of the pre-Gila rocks in the southern two-thirds of the map area have suffered hydrothermal alteration significantly related to the copper mineralization. The effects of the alteration decrease outward from a central area of greatest intensity. Altogether, four closely related types of alteration have been distinguished and mapped, and their areal distribution is roughly concentric (types 1 to 4, pl. 1). The boundaries between types are gradational and are necessarily approximate, as shown on the maps, except for the boundary between types 2 and 3 which coincides with the diabase dike southeast of Red Hill. In the main, however, the types are easily recognized on the surface simply by the color of their outcrops: type 1 is very light gray, 2 is brick red, 3 is a brownish or subdued red, and 4 is dark gray.

The most intense rock alteration (type 1) is in an oval area, about 700 by 800 feet, along the secondary road east of Red Hill. The monzonite porphyry in this area has been completely altered, and its weathered outcrops are of a prevailingly light gray color, somewhat stained in places with iron oxide. This rock consists mainly of hydrothermal clay minerals, especially kaolinite with alunite.

Outcrops of very red, hydrothermally altered rock (type 2) occur around this central clay area and are particularly prominent on Red Hill. At depth this rock is highly pyritic, as shown by churn drill cuttings. In general, this type of alteration is much like type 1, with more abundant hydromuscovite and chlorite, and with the addition of much pyrite at depth, which is oxidized to hematite to a depth of 500 feet.

Type 3, south of the diabase dike, is coincident with the area of important copper mineralization, as it is known from surface exposures and from the churn drill holes put down by the Bureau of Mines. At the surface, the mineralized rock is dark brownish red, rather than the brick red of the rocks north of the dike. Chrysocolla coats even the most minute fracture surfaces of the better mineralized rock. At depth the mineralized rock is essentially a quartz-sericite-pyrite-chalcopyrite aggregate, with chalcocite replacing most of the chalcopyrite in the secondary sulfide zone. Biotite has completely disappeared from most of the mineralized rock, but pseudomorphs of muscovite and chlorite are not uncommon. As in the other types, there are many alteration products, including kaolinite, hydromuscovite, beidellite, leucoxene, and rutile.

A marginal, less intense alteration (type 4) is found in a single outcrop south of the area of more intense alteration, and in the upper parts of the more southerly drill holes. Drill cuttings of the unweathered porphyry appear fresh under the hand lens, but in thin section the groundmass especially is a complex of alteration products, with secondary biotite, epidote, zoisite, and chlorite more abundant than in the other types. Similar alteration is found on the north side of the area where both quartz monzonite and monzonite porphyry are well exposed north of Red Hill. Here the red outcrops of type 2 fade rather abruptly to the dark-gray porphyry of type 4, with no type 3 alteration or copper mineralization between them. In the dark-gray porphyry north of Red Hill, most of the plagioclase and biotite phenocrysts are partially replaced by spots of epidote. The groundmass is a complex of epidote, sericite, and secondary biotite. The alteration is less prominent in the coarse-grained quartz monzonite in which epidote is confined largely to fractures. Farther north this epidotic alteration fades out, but some alteration continues toward the Mammoth-St. Anthony mine where more severe alteration occurs.

A close relationship is indicated between the rock alteration and the primary sulfide mineralization. The primary sulfides, predominantly pyrite and chalcopyrite with minor molybdenite, are systematically distributed in the altered rocks below the zone of weathering. Abundant pyrite is particularly characteristic of type 2 alteration, although pyrite is evidently widespread throughout the moderately and intensely altered rocks. Abundant chalcopyrite has been found only in the belt of type 3 alteration that crosses the map area south of Red Hill, where it is associated with considerable pyrite and minor amounts of other sulfides. The data available from deep drill holes in this belt indicate that primary copper values range from several tenths of 1 percent to several percent, and may average about half a percent copper. Possibilities for minable bodies of copper ore within the map area are largely confined to this belt, although chalcopyrite persists in smaller amounts into the type 2 alteration to the north and the type 4 alteration to the south. The copper mineralization has been found equally in quartz monzonite and monzonite porphyry; thus far there is no evidence of any consistent difference in copper values in the two rocks.

The hypogene mineralization and alteration affected principally the quartz monzonite and monzonite porphyry, but available evidence suggests that the diabase was also altered and mineralized. The felsite is essentially barren and cuts the mineralized rock. The Gila conglomerate is not altered and shows no evidence of sulfide mineralization. It is believed, therefore, that the Gila is post-mineral, and that the faults which cut it also displace the belts of altered and mineralized rock.

Supergene oxidation and enrichment.—Weathering processes have affected all of the rocks of the area and have developed the characteristic colors on surface exposures of the four types of altered rock. Of greatest significance, however, are the effects of weathering on the copper deposits.

The present water table is somewhat irregular but generally near an elevation of 2,500 feet above sea level. The depth of oxidation varies greatly, some oxidation being recognized as deep as 1,700 feet beneath the surface, suggesting that in the past the water table may have been much deeper, for short periods at least. In the oxidized zone of the copper belt (pl. 3, sec. B-B', 3a) most of the sulfide minerals have been oxidized and chrysocolla is now the predominant copper mineral. Residual sulfides are encountered, however, and assays indicate small amounts of sulfide throughout. The copper values have probably been diminished and redistributed to some degree by leaching. Average values in the oxidized ore are on the order of three-quarters of 1 percent, but relatively few individual assays exceed 1 percent copper. In the mineralized outcrop (pls. 1, 3) chrysocolla coats seams and fractures, and is relatively abundant in the shattered diabase dike and in fractured rock adjacent to faults. The Gila conglomerate also contains some chrysocolla that has been deposited by weathering solutions in porous zones adjacent to contacts with mineralized rock.

An irregular zone below the oxidized ore has been enriched in copper by weathering solutions which deposited chalcocite and other secondary copper minerals as replacements of primary pyrite and chalcopyrite. The chalcocite ore averages on the order of 1 percent copper, and typically contains, in addition to chalcocite, minor amounts of covellite, bornite, and native copper, plus more or less residual pyrite and chalcopyrite. The zone of enrichment is not everywhere a single, simple zone, for oxidized areas occur within it and the secondary minerals occur with primary sulfides in local patches above and below. The thickest and richest parts of the chalcocite zone have been encountered in drill holes within the sericitic alteration (type 3), but leaner extensions of the chalcocite zone are found beyond these limits, particularly to the north.

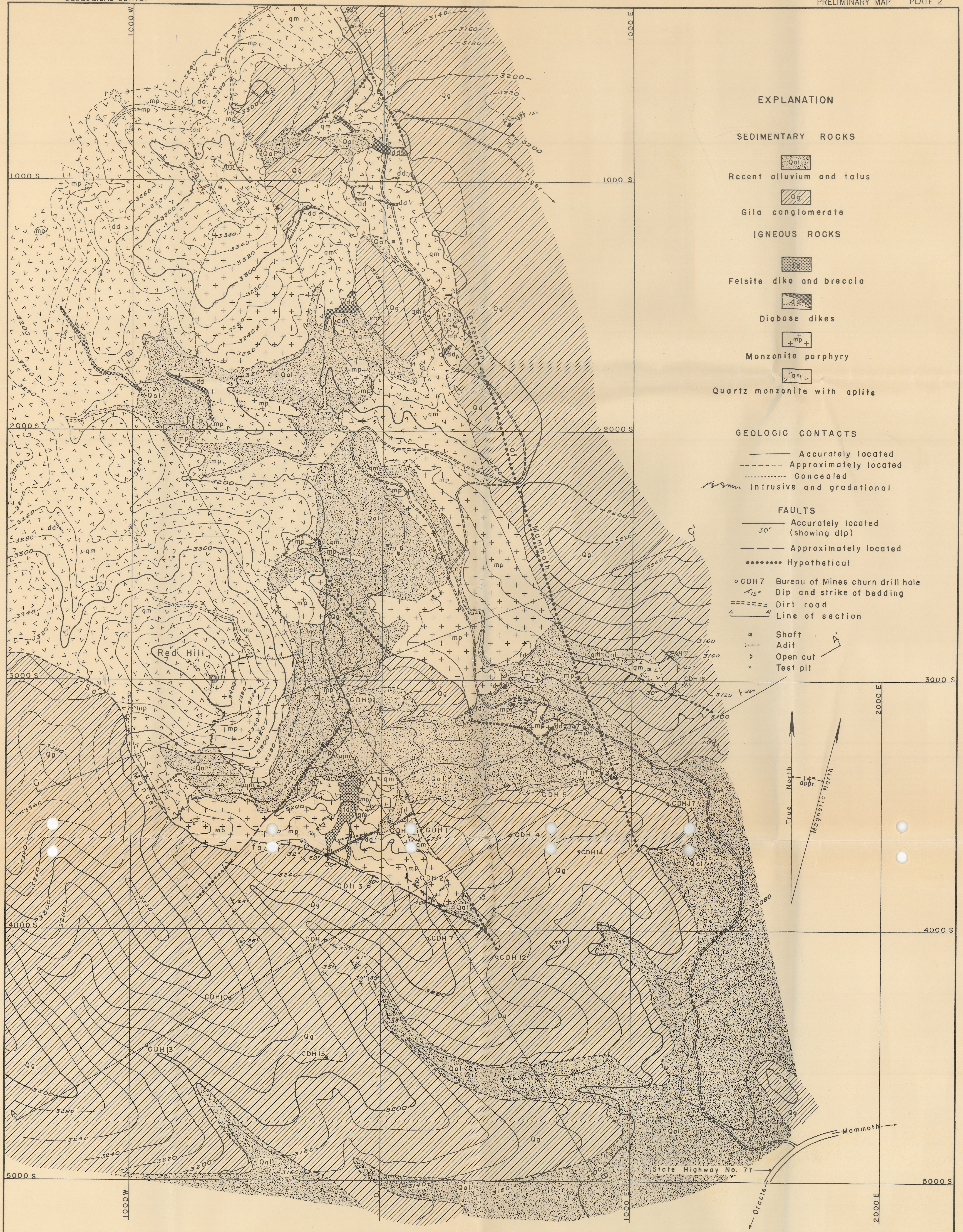
The zones of oxidation and enrichment vary so much with respect to the present surface that it seems probable that they were developed during an earlier erosion cycle. Although the San Manuel deposit resembles many other porphyry copper deposits in that copper has been leached from the oxidized zone to enrich a secondary sulfide zone, it is rather unique in the relative abundance of chrysocolla in the oxidized zone, in the persistence of copper minerals in the weathered outcrop, and in the fact that the oxidized ore appears to be richer than the primary sulfide. These peculiarities suggest a possibility that the present oxidized zone may have developed by oxidation of a pre-existing chalcocite zone.

The ore body.—The San Manuel ore body appears to be a tabular mass dipping steeply southeast. Its limits have not been definitely outlined by the Bureau of Mines drilling, but, as shown by the accompanying maps and sections, the ore body extends east and west beneath a thick cover of Gila conglomerate.

The ore body appears to occupy a definite position in the pattern of hydrothermal alteration of the surrounding rocks. It coincides substantially with a tabular mass of sericitized rock, is underlain by a steep footwall of intensely altered and pyritized rock, and is overlain by a steep hanging wall of less intensely altered rock.

The upper part of the ore body is oxidized to considerable depths, averaging perhaps 700 feet, the depth of oxidation increasing in general from west to east. A zone of enriched chalcocite ore underlies the oxidized zone. The chalcocite zone has been most thoroughly explored in the central part of the drilled area, where its thickness averages roughly 250 feet. Primary sulfides occur beneath the chalcocite zone, but the character of the primary sulfide zone is not well known, for relatively few drill holes have penetrated it more than 100 feet. Several steep cross faults probably displace the ore body with small lateral offsets, and may displace the chalcocite zone vertically as much as several hundred feet.

The size of the ore body will not be fully known until its limits can be determined by further exploration. But in December 1944 announcements were published that drilling had indicated 30,000,000 tons of low-grade ore containing an average of 0.8 to 0.9 percent copper and small amounts of molybdenum and gold. The part of the ore body explored by the Bureau of Mines drill holes is about 400 feet wide and 2,000 feet long. Several holes show the existence of ore at depths of 1,000 feet, and one hole was in ore at a depth of 1,845 feet. If more detailed data should prove the ore body to have dimensions of 400 by 2,000 by 1,000 feet, the tonnage would be inferred as about 64,000,000. This figure may be increased by drilling now being carried on by private companies.



Red Hill is
N 3200'
E 460'
T 8 S
R 16 E

UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY

GEOLOGIC AND TOPOGRAPHIC MAP
OF THE
SAN MANUEL COPPER DEPOSIT AND VICINITY
OLD HAT MINING DISTRICT PINAL COUNTY, ARIZONA
1944

Contour interval: 20 feet Datum is mean sea level

0' 100' 200' 400' 600' 800' 1000'

Churn Drill Holes by
United States Bureau of Mines (Project-1466)

Geology by
N.P. Peterson, D.H. Kupfer, G.M. Schwartz, and E.E. Gould
Geological Survey

UNITED STATES DEPARTMENT OF THE INTERIOR
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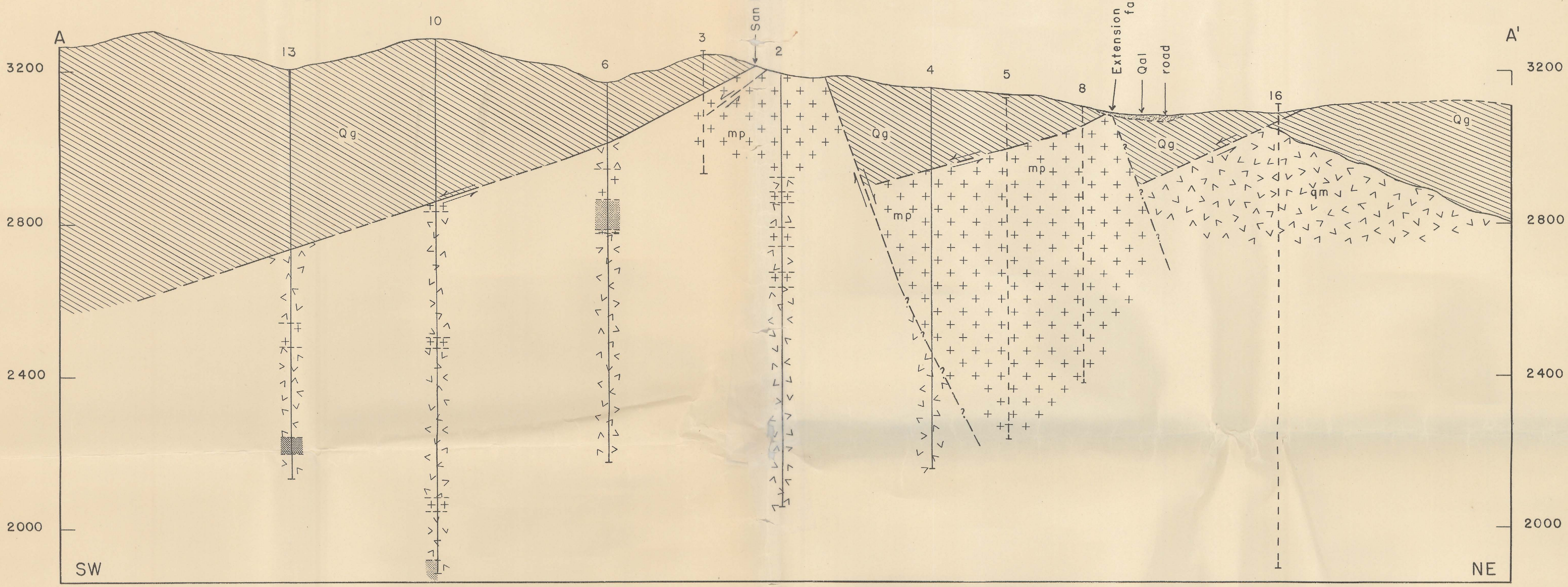
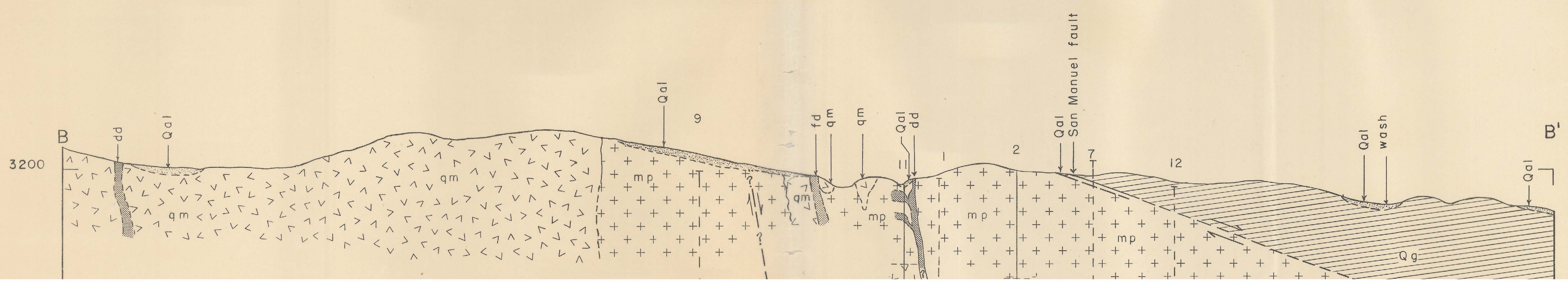
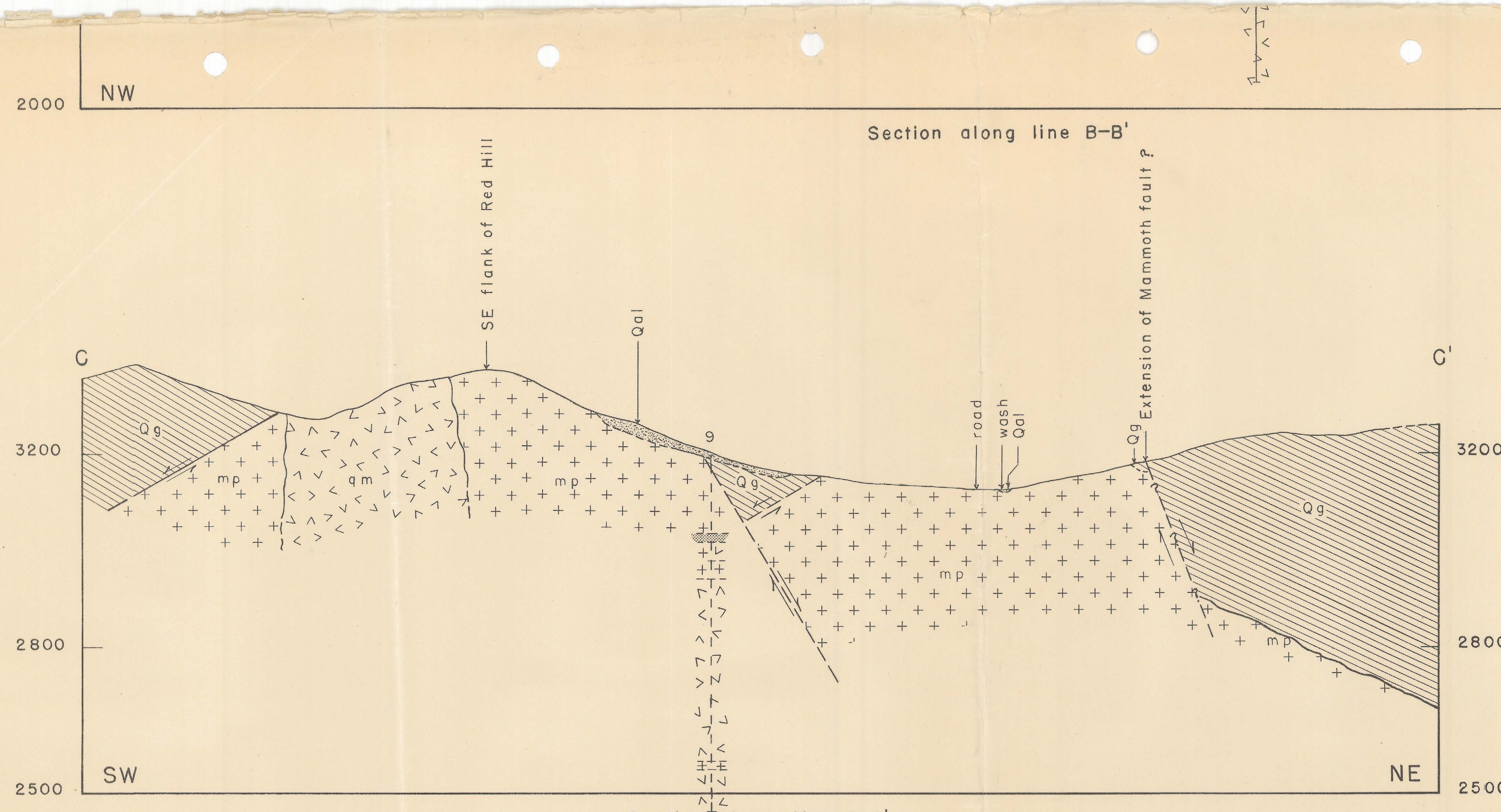
STRATEGIC MINERALS INVESTIGATIONS
PRELIMINARY MAP PLATE 4



Section along line A–A'



Section along line B-B'



Section along line C-C'

EXPLANATION

SEDIMENTARY ROCKS

- Qal — Alluvium and talus
- Qg — Gila conglomerate (showing apparent dip)

IGNEOUS ROCKS

- fd — Felsite
- dd — Diabase
- mp — Monzonite porphyry
- qm — Quartz monzonite with aplite

FAULTS

- Known fault (solid line = accurate) (dashed line = approximate)
- Hypothetical fault

CHURN DRILL HOLES by U.S. Bureau of Mines (Project 1466)

- 6 — Vertical drill hole on line of section
- 3 — Vertical drill hole projected to section

DISTRIBUTION AND STRUCTURE OF ROCK FORMATIONS

VERTICAL SECTIONS THROUGH THE SAN MANUEL COPPER DEPOSIT AND VICINITY

0' 100' 200' 400' 600' 800' 1000'

Geology by
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