Geology and Ore Deposits of the Bagdad Area Yavapai County Arizona

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By C. A. ANDERSON, E. A. SCHOLZ, *and* J. D. STROBELL, JR.

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A study of the Bagdad porphyry copper deposit and its geologic setting

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By C. A. Anderson, E. A. Scholz, and J. D. Strobell, Jr.

ABSTRACT

The Bagdad area covers 38 square miles in the mountainous region of west-central Arizona. The topography is that of a combination of lava mesas and mountains cut by the deep canyons of Boulder and Copper Creeks.

The oldest rocks in the area have been correlated with the Yavapai series of pre-Cambrian age, which has been subdivided into three formations. One, the Bridle formation, consists of metamorphosed andesitic and basaltic lava flows and intercalated water-deposited tuffaceous beds and terrigenous sediments; the total thickness is more than 3,000 feet. The Bridle formation probably is older than a second formation, the Butte Falls tuff, because rhyolite tuff beds occurring near the base of the Butte Falls tuff are similar to some near the top of the Bridle formation. The Butte Falls tuff is composed of water-deposited sediments of volcanic source, and some beds probably represent accumulations of pyroclastic material; its total thickness is about 2,500 feet. The Butte Falls tuff grades upward into the Hillside mica schist, a unit consisting of metamorphosed sandstone and shale; its total thickness is 3,000 to 4,000 feet.

The three formations of the Yavapai series are intruded by pre-Cambrian igneous rocks of diverse composition. The oldest of the igneous rocks is rhyolite; there are two facies: one, the King Peak rhyolite, is nonporphyritic in texture, whereas the other, the Dick rhyolite, contains quartz phenocrysts. The Dick rhyolite probably is the younger. The rhyolite and the rocks of the Yavapai series are intruded by widespread masses of gabbro and related quartz diorite and diabase. Large masses of alaskite porphyry intrude the gabbro and older rocks in the western half of the Bagdad area. Two facies of alaskite porphyry have been distinguished: one contains a microcrystalline, and the other, a finely phanerocrystalline groundmass. Two belts of rocks adjacent to the Bridle formation have characters which indicate that they are intrusive masses of alaskite porphyry contaminated by partly assimilated rock material derived from the neighboring Bridle formation. The adjacent lava of this formation shows evidence of soaking by alaskitic material but retains some of its volcanic structures, such as amygdules. Small intrusive masses of granular alaskite appear next to one of the gabbro bodies, and some mixed alaskite-gabbro rocks have been formed. Granodiorite gneiss crops out in the northern and eastern parts of the area, and evidence suggests that the gneiss is younger than the gabbro.

The closing episode of pre-Cambrian intrusive activity was marked by the intrusion of granite. Two facies have been distinguished in the Bagdad area. The most widespread, the porphyritic Lawler Peak granite, contains large orthoclase phenocrysts. In the northwest corner of the area these phenocrysts generally show some orientation, which indicates that the partly crystallized magma was subjected to east-west compression, probably regional. The Lawler Peak granite has intimately intruded and soaked many of the older rocks and formed masses of mixed rocks. In local facies of this granite, muscovite is the only mica. The other granite, the fine-grained Cheney Gulch granite, occurs in the southern half of the area as small masses intrusive into the Lawler Peak granite. Both granites are intruded by dikes and masses of aplite-pegmatite. One of the larger masses is exposed for nearly a square mile.

The Grayback Mountain rhyolite tuff rests on an eroded surface of alaskite porphyry and about 500 feet of tuff are exposed. By analogy to the age of similar rocks elsewhere in Arizona, the age of this tuff is probably Late Cretaceous or early Tertiary. The tuff is intruded by rhyolite dikes that are in turn, intruded by quartz monzonite, probably of Late Cretaceous or early Tertiary age. The quartz monzonite crops out in a series of stocks and plugs; the largest stock at Bagdad is mineralized with copper and contains the ore body of the Bagdad mine. The dikes of diorite porphyry and quartz monzonite porphyry are younger than the quartz monzonite.

During the Pliocene and Pleistocene, a surface of considerable relief was partly buried by the Gila(?) conglomerate and intercalated basalt flows. These flows have been divided into two formations. The older is the Wilder formation that includes some volcanic cones, intrusive plugs, and basaltic tuff, and the younger is the Sanders basalt that caps the present mesas; to the south the basalt is separated from much of the underlying Gila(?) conglomerate by a bed of rhyolite tuff.

The structure of the rocks of the Yavapai series is interpreted as a syncline, and in the southern part of the area the western limb is overturned. The folded structures were faulted and igneous rocks were intruded along the faults, indicating that folding and faulting of the Yavapai series took place before the pre-Cambrian igneous intrusive activity.

The effect of thermal metamorphism is found in rocks adjacent to the Lawler Peak granite, whereas dynamic metamorphism locally has caused foliation of all the pre-Cambrian rocks except the Cheney Gulch granite and the aplite-pegmatite. The history of metamorphism was long and varied, although most of the effects of metamorphism that were observed probably originated during the emplacement of the Lawler Peak granite. Foliation is generally parallel to the bedding in the rocks of the Yavapai series. Lineation was observed, but the relationship of lineation to the major fold axes is in doubt. The grade of metamorphism ranges from the low-grade chlorite zone to the high-grade sillimanite zone.

One or possibly two periods of faulting preceded the intrusion of the pre-Cambrian igneous rocks. Two or probably three periods of faulting succeeded the emplacement of the pre-Cambrian Lawler Peak granite. The faults younger than this granite

include the northward-trending normal Mountain Spring and Hillside faults, which may have been connected before the intrusion of the quartz monzonite. The eastward-trending White Spring fault is younger than the Lawler Peak granite, and recurrent movement occurred along it after the intrusion of the quartz monzonite. The other faults in the area are younger than the Gila(?) conglomerate, and include the northward-trending normal Hawkeye and Bozarth faults having displacements of 100 to 300 feet. These two faults are probably connected in an area covered by an appreciable blanket of talus and soil. Comparable displacement also took place along the Hillside fault after the deposition of the Gila(?) conglomerate. Several faults of small displacement cut the Sanders basalt and the underlying Gila(?) conglomerate.

The structures in the Bagdad mine show a definite orientation in the northwest and northeast quadrants. The trend of the quartz monzonite stocks is N. 70° E., and an aplitic dike in the Bagdad mine strikes N. 40° W. The generalized trend of the diorite porphyry dikes is N. 60° E. and the trend of the quartz monzonite porphyry dikes is N. 20° W. Quartz-pyrite-chalcopyrite veins trend N. 50°–70° E. and N. 40° W. The minor mineralized fractures are concentrated along one of three directions, N. 70° E., N. 20° E., and N. 40° W. Many postmineral faults strike N. 70° E. but a few strike N. 40° W. It is concluded that the northwest and northeast trends of rupture represent conjugate shears, and the minor mineralized fractures that carry the bulk of the copper minerals in the Bagdad mine represent secondary breaks of conjugate shears and are directly related to the larger fracture pattern.

Breccia pipes and dikes are limited to the western half of the area and are not uniform in size and form. Some are composed of a heterogeneous mixture of rocks and contain abraded "cobbles" derived from the underlying rocks. The materials of the pipes range from permeable breccias cemented by quartz, pyrite, and chalcopyrite to breccias that are tightly packed rock fragments in a matrix of fine rock powder. The pipes and dikes range in age from before accumulation of the Grayback Mountain rhyolite to after intrusion of the quartz monzonite porphyry.

Mining in the Bagdad area began in 1887, when gold-silver-lead ore was shipped from the Hillside mine, and fairly regular production continued until 1912. The mine reopened in 1934 and in 1937 zinc became an important recoverable metal. The Copper King mine was active in 1917–20, 1925–27; after 1942 zinc was the important metal recovered. Copper has been produced at Bagdad since 1929, except for the period 1931–34. Mining on a large scale began in 1943 and in 1951 the daily production reached 3,500 tons per day. Gold, silver, lead, copper, and zinc have been produced at different times from small mines in the area. Primary zinc ore has been mined from the Old Dick mine since 1947. The total value of metals produced in the Bagdad area from 1887 to 1951, inclusive, has been more than $31,000,000.

The copper minerals in the Bagdad mine occur in minor fractures and are disseminated in the quartz monzonite. Hypogene alteration and mineralization of the quartz monzonite resulted in the formation of quartz, orthoclase, albitic plagioclase, leafy biotite, sericite, pyrite, chalcopyrite, and molybdenite. Supergene enrichment formed a chalcocite blanket before accumulation of the Gila(?) conglomerate, and the dominant northeast faults were important in controlling deposition of the chalcocite. Maroon "relief" indigenous iron oxide in the leached outcrops indicates the distribution of the chalcocite. Transported yellow-brown iron oxide and jarosite indicate the distribution of the primary chalcopyrite and pyrite. The Hawkeye fault marks the western boundary of the chalcocite blanket.

Copper, lead, zinc, and silver are present in the Old Dick and Copper King mines in massive-sulfide replacements of the Bridle formation, and supergene enrichment has formed some shipping ore. Fissure veins containing gold, silver, lead, zinc, and copper are of importance, whether or not supergene enriched. Both oxidized and sulfide ores have been mined from the Hillside vein. The copper-lead-zinc-gold-silver mineralization was related to the intrusion of quartz monzonite in Late Cretaceous or early Tertiary time.

Low-grade wolframite-bearing veins of pre-Cambrian age are a potential reserve of tungsten; mining of these veins began in 1952 at the Tungstona mine.

Premium payments for copper, lead, and zinc stimulated mining in the area during and after World War II. Large indicated and inferred reserves of copper are present around the Bagdad mine. Prices of metals will be of importance in determining future mining activity in the Bagdad area.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The town of Bagdad, in west-central Arizona in Yavapai County, is 42 miles west by airline from Prescott, the county seat, but by road the distance is 68 miles. The area mapped geologically (pl. 3) covers about 38 miles and is referred to in this report as the Bagdad area (fig. 1). It lies between longitude 113°08′10″ W. and 113°15′45″ W. and the northern border is latitude 34°38′20″ N. The southern border lies between latitude 34°32′35″ N. and 34°33′15″ N.

The Bagdad area lies in the southwestern part of the Eureka mining district and contains most of the significant mines and prospects of this district. The exceptions are the tungsten mines in the Camp Wood area 18 miles to the northeast, gold mines and prospects 15 miles to the southeast along the Santa Maria River, and tungsten and copper-zinc mines 10 miles to the south and southeast from Bagdad.

The Phoenix branch of the Atchison, Topeka & Santa Fe Railway Co. is to the east, and an excellent graded gravel road connects Bagdad with Hillside, 26 miles to the southeast, the nearest railroad station. Dirt roads connect Hillside with Congress Junction, 22 miles to the south and with Kirkland Junction, 20 miles to the east. Congress Junction and Kirkland Junction are on paved U. S. Highway 89 between Prescott and Phoenix. Seven miles southeast from Bagdad on the Hillside road, a dirt road in fair condition circles to the south of Bagdad, as far as the Big Sandy River, where another dirt road extends north to Kingman.

Fair roads connect Bagdad with the Copper King, Old Dick, and Mountain Spring mines and the Mammoth prospect, all to the south. A dirt road in good condition leads north to the Hillside mine and a branch road leads to the Comstock-Dexter mine. A dirt road

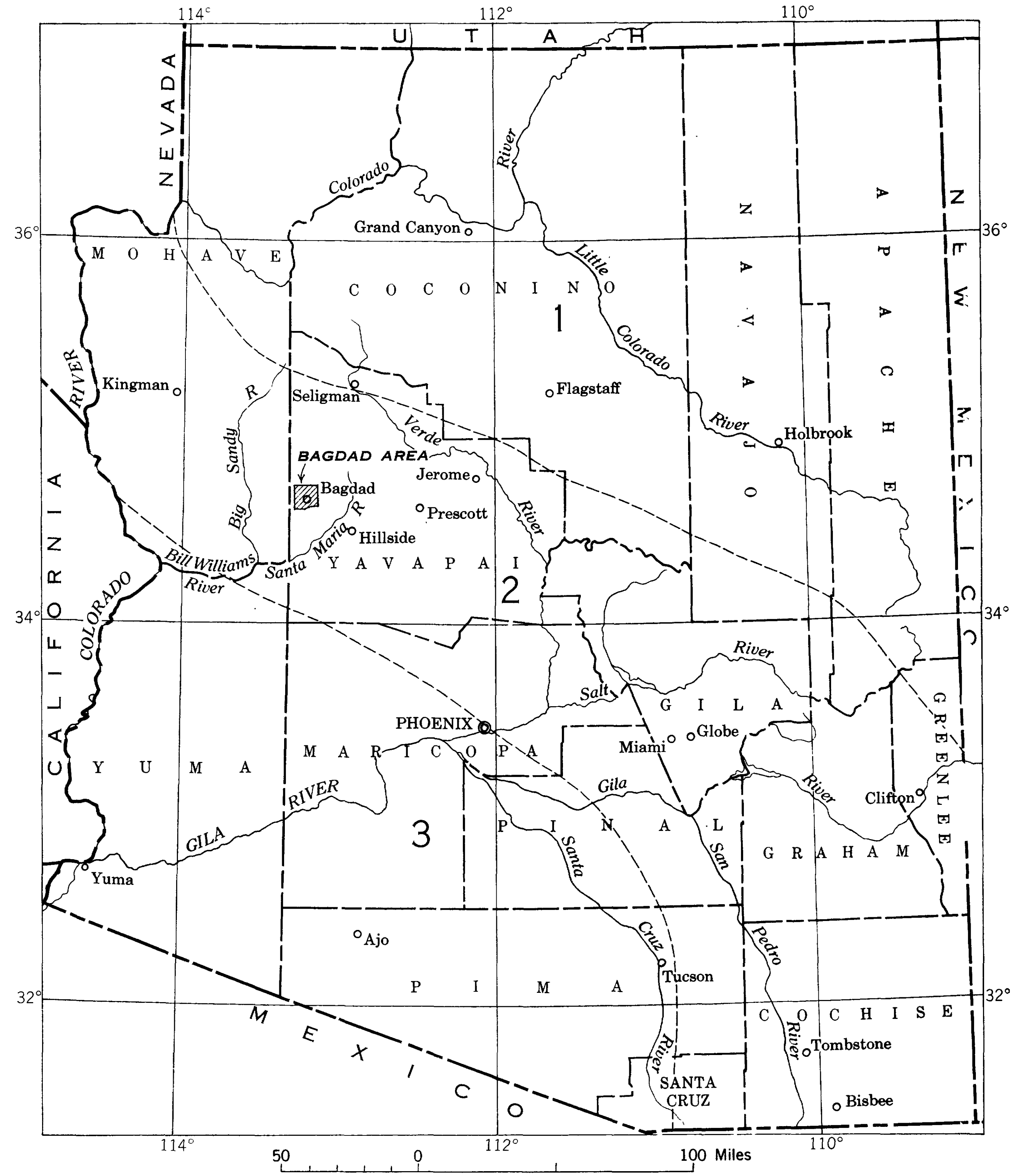


FIGURE 1.—Index map of Arizona, showing the location of the Bagdad area and approximate outline of the three principal physiographic regions: (1) plateau region; (2) mountain region; and (3) desert region. (After Ransome, 1919, p. 27.)

turns south of Nelson Mesa and passes through Wild Horse Basin, east of the mapped area, to the Black Pearl tungsten mine near Camp Wood. A dirt road in poor condition follows Copper and Boulder Creeks down from Bagdad to the Burro Creek pump station, 7 miles west of Bagdad. A dirt road having local steep grades follows the powerline from northwest of the Copper King mine to the north side of Mammoth Wash.

A number of trails have been built to several isolated prospects, but many of these are in disuse and are difficult to follow. The trail down Boulder Creek from the Hillside mine and a trail from Mineral Creek to the Copper King mine are in good condition.

Bagdad, the only settlement in the area, had a population of about 1,500 in 1952. Telephone service to Hillside and Prescott, and a telegraph office at Hillside provide outside communication. Three cattle ranches are in the area. Small mining camps formerly existed at the Comstock-Dexter and Hillside mines, but the buildings were removed in 1944–45.

TOPOGRAPHY

The topography in the Bagdad area is a combination of mesas and mountains. The northern and northwestern margins encroach on an area of extensive lava mesas; the middle part is occupied by a crescent-shaped belt of smaller lava mesas extending from Nelson Mesa on the east to Black Mesa on the west. The altitude of the mesas increases eastward from 3,750 to 4,500 feet. The northeast corner is mountainous, culminating in Lawler Peak at an altitude of 4,850 feet. The southern half is composed of rolling hills ranging in altitude from 3,500 to 4,000 feet and rising gradually to the summit of Grayback Mountain (5,133 feet) in the southwest corner, the highest peak in the area.

Boulder Creek has cut a deep canyon into the mesas and the underlying basement rocks, essentially along the western and northern mesas. The relief is 1,200 feet to the west and about 1,000 feet to the north. In its western course the creek is at grade, flowing on wide deposits of river wash. Copper Creek, which joins Boulder Creek in the west-central part of the area, has cut a deep canyon in the lower part of its course, but in the headwaters the relief is not as great. These two streams and their tributaries drain much of the area and the tributaries flow in deep canyons in their lower courses. Bridle Creek and its tributaries drain the southeast corner of the area, but the relief is less.

Ransome (1919, p. 27) divided the State of Arizona into three physiographic units: the plateau region to the northeast, the desert region to the southwest, and the mountain region between them. Butler and Wilson (1938a, p. 9) included the mountain and desert regions in the Basin and Range province; they pointed out that the mountain region forms a belt 60 to 100 miles wide and contains most of the large ore deposits in Arizona. Ransome described the mountain region as characterized by many short ranges, nearly parallel to each other and parallel to the curved margin of the plateau region. The individual ranges are separated by valleys which are narrow, if their width is compared with their lengths or with the wide undrained plains in the desert region. The Bagdad area is in the northwestern part of the mountain region and about in the middle of the belt (fig. 1). No name is in common usage for the mountains in the Bagdad area, but the individual mesas and peaks are named.

CLIMATE AND VEGETATION

Rainfall records, 1930–51, inclusive, show that the annual rainfall averaged 14.36 inches, 7.31 inches is the minimum and 25.54 inches is the maximum (table 1). The rainfall is seasonal, the winter rains fall from December through March and the summer rains from

TABLE 1.—*Rainfall data, Bagdad, Ariz.*

[Furnished through the courtesy of W. D. Deacon, weather observer, U. S. Weather Bureau, Bagdad, Ariz.]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1930	2.98	0.65	3.03	0.04	1.22	0.14	1.57	0.85	1.69	0.95	1.98	0	15.10
1931	.54	4.31	.11	1.37	.25	1.07	1.83	8.25	.84	.41	1.81	4.43	25.22
1932	.27	6.90	.17	.03	.16	.16	1.50	1.20	.74	.33	0	2.23	13.69
1933	3.06	.30	.03	.93	.13	.39	1.23	.73	.39	.58	1.04	.61	9.42
1934	.63	1.04	.12	.39	.06	.09	.02	4.13	.16	.14	1.02	2.69	10.49
1935	3.26	4.59	2.00	.25	2.06	0	.35	3.41	1.54	.04	.21	.41	18.12
1936	.44	2.66	1.31	.34	0	.01	2.46	2.11	1.87	.28	.31	3.76	15.55
1937	3.22	3.11	1.74	.01	.38	.23	1.94	2.42	1.02	0	.05	1.72	16.74
1938	.65	2.17	3.22	.05	.08	.55	.36	1.51	.44	.15	.02	3.37	12.57
1939	1.51	1.45	.80	.48	0	0	.56	1.32	6.70	.06	1.21	.35	14.44
1940	1.05	1.93	1.19	.84	Tr.	.14	Tr.	.69	3.90	1.24	1.37	2.49	14.84
1941	2.30	2.90	4.56	3.47	.20	.03	2.05	2.05	3.36	1.79	.57	2.26	25.54
1942	.44	.93	.52	1.28	0	0	1.83	1.21	0	.19	.21	.71	7.32
1943	2.03	.69	1.23	.92	0	0	.53	1.63	2.26	1.28	0	1.21	11.78
1944	.55	6.28	1.36	.83	.05	0	.03	1.04	1.36	.76	2.32	1.95	16.53
1945	1.23	1.38	2.93	Tr.	Tr.	0	.79	2.57	.02	1.91	0	2.35	13.18
1946	.60	.05	1.30	1.29	.07	0	4.16	1.29	1.16	1.75	1.78	2.02	15.92
1947	.38	.11	Tr.	Tr.	.32	0	.30	3.80	.47	.34	.26	1.95	7.93
1948	0	.85	.72	.25	0	.10	2.63	1.03	.09	.97	0	2.58	9.22
1949	5.31	0	0	.73	.09	.60	1.21	.40	1.60	1.29	.61	1.21	13.05
1950	.77	1.14	.28	.19	0	0	3.99	.05	.69	0	.15	.05	7.31
1951	1.87	.69	.28	3.43	1.35	0	1.15	8.07	.65	1.77	1.03	1.78	22.07
Average	1.51	2.01	1.23	.78	.29	.16	1.39	2.26	1.41	.75	.74	1.83	14.36

July through September. August has the highest monthly average, 2.26 inches, and the monthly average for February is 2.01 inches. The summer rains are commonly of the thunderstorm type, and infrequent cloudbursts result in a short period of torrential streamflow. High rates of streamflow can be expected during the winter rainy season, when the rainfall is more evenly distributed throughout the area.

The summers are warm, the maximum temperatures exceeding 100°F during short hot spells. Freezing temperatures occur in the winter having occasional temperatures as low as 10°F. Light snowfall is common in the winter months, but the snow rarely lasts longer than a day except on the higher peaks and mesas.

The vegetation is typical of the transition zone between the desert region and high parts of the mountain region where pine forests grow. The altitude in the Bagdad area is too low for pines, but juniper, mountain mahogany, scrub oak, and mountain laurel are conspicuous. A variety of cacti grow in the area, ranging in size from the giant saguaro to the small hedgehog and pincushion varieties. Pricklypear and several varieties of cholla are abundant. Thorny shrubs, such as ocotillo, catclaw, mesquite, palocristo, and paloverde, are typical of the region, and several varieties of yucca flourish in the area. Sycamore and cottonwood trees grow in the major canyons. During the spring, after heavy winter rains, flowering plants, such as the mariposa, verbena, poppy, pentstemon, mallow, and wild marguerite, are plentiful.

FIELD WORK

The field work began in November 1943 and continued until August 1945. No topographic maps were available at the beginning of the mapping, and the geology was plotted on aerial photographs enlarged from a scale of 1:40,000 to a scale of 1:12,000. At the completion of the geologic mapping a contour map on the scale of 1:14,400 was made by the Geological Survey, and the important geologic contacts were transferred to enlargements of the photographs from which diapositives were made for use in the multiplex aeroprojector. The geology was then transferred to the contour map by means of the multiplex projector. Many contact lines closely spaced on the photographs interfered with the stereoscopic vision of the multiplex operator, so that other geologic contacts were transferred from the field sheets to the contour map, using the previously plotted contacts and topography as guides for location. Little loss of accuracy results from plotting details later, providing important contacts are plotted by use of the multiplex.

The multiplex method of plotting geology allows beginning of geologic mapping in advance of the preparation of a contoured base map, and in the Bagdad area, precise location on the aerial photographs was possible because of the excellence of the photographic details. Some of the cartographic units could be distinguished easily, because color differences in the rocks are sharply defined on the photographs The plotting probably is as accurate as could be obtained by the conventional methods of geologic mapping on a contour map of the same scale as the photographic enlargements used in the field. Additional time is involved, however, in the compilation of geology on special photographs for the preparation of diapositives, and for the checking and plotting of additional geology on the contour map.

All the writers had equal responsibility in the preparation of the geologic map and in the study of the Bagdad mine. E. A. Scholz studied the Hillside, Copper King, Stukey, Cowboy, and Mountain Spring mines and the Mammoth prospect. J. D. Strobell, Jr., studied the Old Dick mine and the tungsten veins. C. A. Anderson and Strobell mapped the Kyeke mine and Black Mesa breccia pipe. Anderson and Scholz studied the other mineralized breccia pipes. Anderson studied the leached outcrops beyond the Bagdad mine and did most of the petrographic work.

The report deals with the information available in 1945, except where noted in the text. Scholz assisted Anderson in July 1952, in the revision of the studies of the Copper King and Old Dick mines, in order to bring the account of these mines up to date.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the cooperation given by all members of the staff of Bagdad Copper Corp., particularly J. W. Still, general manager, and his successor, E. R. Dickie Entry to the mine and access to all records were freely given. Mr. Still, who is familiar with the Bagdad mine, was very helpful in the early stage of the work. William Mueller was a fountain of important information on the early history of the exploration at Bagdad. K. L. Erickson, superintendent, supplied helpful data on the Old Dick mine. Valerio Rossi permitted entry to the Copper King mine and furnished several smelter returns of recent shipments of ore. Julius Commod's familiarity with the pegmatite mineral localities saved the writers important time. H. R. Wood, of Prescott, supplied much valuable data on the early history of the area, particularly with reference to the Hillside mine.

The work profited from visits in the field by R. S. Cannon, Jr., and James Gilluly of the Survey. B. S. Butler kept in constant touch with the work in all of its phases, and his critical comments, both in the field and by letter, have been very valuable.

PREVIOUS WORK

Very little geologic literature has been published that deals with the Bagdad area but several private geologic reports have been made about the property of the Bagdad Copper Corp. and its predecessors, and these have aided the present studies. The following articles, listed chronologically, have been published:

1890. Storms, W. H., Arizona's new bonanza: Eng. and Min. Jour., v. 50, p. 162–163.
A brief discussion of the Hillside mine with comments on the grade of the ore that was being shipped at that time.

1919. Ball, S. H., and Broderick, T. M., Magmatic iron ore in Arizona: Eng. and Min. Jour., v. 107, p. 353–354.
Brief description of the geology of the Bagdad area with special emphasis on the titaniferous magnetite occurring in metagabbro. Presents three chemical analyses.

1929. Yost, H. W., Production plans of Bagdad Copper Corporation: Min. Jour., v. 13, no. 6, p. 5.
Describes a proposed method of copper recovery for Bagdad by means of flotation, roasting, leaching, and electrolytic precipitation of copper.

1933. Singewald, J. T., Titaniferous magnetites—Arizona, *in* Ore Deposits of the Western States (Lindgren volume): Am. Inst. Min. Met. Eng., p. 511–512.
Essentially the same information as in Ball and Broderick (1919).

1934. Thomas, G. G., Pilot mill flotation work at the property of the Bagdad Copper Corporation, Hillside, Arizona: Inst. Mining Metallurgy, Trans. 1933–34, p. 705–748.
A summary of the geology of the Bagdad mine is given, based on private reports. The main part of the paper deals with flotation results of the pilot mill.

1937. Hoagland, Jackson, Comstock-Dexter's plan for production: Min. Jour., v. 21, no. 8, p. 3–4.
Early history of the Comstock-Dexter mine is given as well as plans for future operation.

1938. Butler, B. S., and Wilson, E. D., Bagdad mine, Eureka district: Ariz. Bur. Mines Bull. 145, p. 98–103.
Excellent brief account of the geology and ore deposits of the Bagdad mine.

1943. Huttl, J. B., Bagdad—Arizona's latest porphyry copper: Eng. and Min. Jour., v. 144, no. 6, p. 62–66.
A description of the mining and milling methods at the start of operations in 1943.

1946. Anonymous, Bagdad makes a comeback: Min. World, v. 8, no. 6, p. 24–28.
Largely a discussion of the glory-hole mining method started in 1945.

1947. Dickie, E. R., Bagdad copper adopts open-pit mining: Mining and Metallurgy, v. 28, no. 481, p. 9.
Concise account of mining history at Bagdad, reasons for abandoning block-caving mining methods in favor of surface-mining methods, and statements of mining costs under new and old methods.

1948. Anderson, C. A., Structural control of copper mineralization, Bagdad, Arizona: Mining Technology (Am. Inst. Min. Eng.), v. 12, no. 2, Tech. Publ. 2352.
Summary of evidence to show that a set of northwest and northeast conjugate shears localized igneous intrusions and fracturing, controlling copper mineralization.

1950. ——— Lead-zinc deposits, Bagdad area, Yavapai County, Arizona: Ariz. Bur. Mines Bull. 156, p. 122–138.
Brief description of the lead-zinc deposits in the Bagdad area.

1950. ——— Alteration and metallization in the Bagdad porphyry copper deposit, Arizona: Econ. Geology, v. 45, p. 609–628.
Concluded that mineralizing solutions brought in sulfur, copper, and potash, and leached lime, soda, and iron from the host rocks.

1951. ——— Older Precambrian structure in Arizona: Geol. Soc. America Bull., v. 62, p. 1331–1346.
Brief account of the pre-Cambrian rocks at Bagdad and relationship to other pre-Cambrian rocks in Arizona.

1951. Vacquier, V., Steenland, N. C., Henderson, R. G., and Zietz, Isidore, Interpretation of aeromagnetic maps: Geol. Soc. America, Mem. 47, p. 31–34.
Discussion of aeromagnetic map of Bagdad area which accompanies report plus generalized geologic map by C. A. Anderson. Mineralized stock at Bagdad shows conspicious negative anomaly; gabbro and associated titaniferous magnetite bodies show high magnetic intensity.

1951. Anonymous, Bagdad learns to truck: Min. World, v. 13, no. 10, p. 14–19.
Good description of pit operations in 1951.

1952. ——— Bagdad expands copper mill—recovers by-product molybdenite—ups copper recovery by pH control: Min. World, v. 14, no. 3, p. 30–33.
Description of mill operations in 1951.

1953. Dickie, E. R., Green, George, Hondrum, Olaf, and Colville, George, New ideas for Bagdad copper: Eng. and Min. Jour, v. 154, p. 88–93.
Outlines plans for expansion of Bagdad mine and mill and gives ore reserves.

GEOLOGY

Most of the rocks exposed in the Bagdad area make up a metamorphosed pre-Cambrian complex of volcanic rocks, tuffaceous rocks, and sedimentary rocks and associated intruded igneous rocks of diverse composition (pl. 3). After considerable erosion, this pre-Cambrian complex was covered by rhyolite tuff and intruded by associated rhyolite dikes of late Cretaceous or early Tertiary age. Later, stocks of quartz monzonite and associated dikes were emplaced. After erosion carved a surface of considerable relief upon these rocks, lava flows and volcanic cones dammed the principal streams, causing deposition of gravels and sands in the main and tributary canyons. This stage in the geologic history culminated in the outpouring of widespread basalt flows, carved into lava mesas by the latest interval of erosion.

The structure of the pre-Cambrian sedimentary and volcanic rocks appears to be, in part, an overturned syncline modified by faults. Some of the rhyolite, gabbro, and granite intrusions were guided along high-angle faults. The normal Mountain Spring fault is younger than the pre-Cambrian granite but older than the quartz monzonite stocks and associated dikes. In the northern part of the area, the Hillside fault is probably an extension of the Mountain Spring fault, and renewed movement occurred after the outpouring of the basalt flows. A parallel normal fault is also younger than the lavas. Several small faults displace the lavas and the underlying conglomerate.

PRE-CAMBRIAN ROCKS

YAVAPAI SERIES

The oldest rocks in the area are a series of lava flows, tuffs, and sedimentary rocks, recrystallized to amphibolite, several types of schist, quartzite, and slate. Age determinations of the younger Lawler Peak granite prove that it is pre-Cambrian, demonstrating that the oldest rocks are also pre-Cambrian. Similar metamorphosed rocks of pre-Cambrian age in the Prescott-Jerome area to the east were named Yavapai schist by Jaggar and Palache (1905). The correlation of the metamorphic rocks at Bagdad with the Yavapai schist is adopted, following the suggestion of Butler and Wilson (1938c, p. 99). Geologic studies made in the Jerome area by S. C. Creasey and C. A. Anderson [1] between 1945 and 1952 have shown that the Yavapai schist is composed of many formations, and they have divided the Yavapai in that area into two groups of rocks and changed the nomenclature from Yavapai schist to Yavapai series, a term that is adopted in this report.

The rocks in the Yavapai series have been metamorphosed, but the primary interest in the study of these rocks has been the stratigraphy and structure, rather than the process of metamorphism. Relict textures and structures were sought as clues to the nature of the original rocks and directions that the tops of the beds faced. Billings (1950) has emphasized the importance of this method in the study of metamorphic terranes, which has been a standard practice of the Geological Survey of Canada in unraveling the geology of the older pre-Cambrian rocks of Canada. In conformance with the procedure of the Geological Survey of Canada, the prefix "meta" has not been used in this report. The relict textures and structures are used as guides for nomenclature, except for one formation of metasedimentary rocks that uniformly is highly metamorphosed, owing to proximity to a younger granite, and for which the term "schist" is used.

In the Bagdad area the metamorphic rocks have been subdivided into three formations. The oldest, the Bridle formation, consists of a metamorphosed series of amygdaloidal and massive flows of andesite and basalt and intercalated sedimentary rocks and rhyolitic tuff. The second formation, the Butte Falls tuff, consists largely of massive- to well-bedded metamorphosed water-deposited tuff and possibly includes some flows. The Butte Falls tuff grades upward into the youngest formation, the Hillside mica schist, which consists of quartz-muscovite schist and muscovite quartzite, representing metamorphosed shale and impure sandstone.

Anderson (1951, p. 1345) has pointed out the difficulty of correlation of individual pre-Cambrian formations for any great distance in Arizona, owing to the repetitious character and lenticularity of the volcanic flows, tuffs, and tuffaceous sedimentary rocks. No correlations of the formations in the Yavapai series at Bagdad with those in the Prescott-Jerome area are attempted.

In the Bagdad area the rocks of the Yavapai series have been folded and faulted and have been intruded by a series of igneous rocks of diverse composition, so that no continuous section includes all three formations, and many of the details of the history and structure could not be obtained. In spite of the metamorphism, many of the original igneous structural features are preserved in the lavas, and evidences of graded bedding, channeling, and crossbedding indicate the tops of the beds in the tuffaceous and sedimentary rocks.

BRIDLE FORMATION

The Bridle formation, named from Bridle Creek, crops out in two belts and forms dark-colored rounded hills. The belt in the southeast corner trends northeastward and has been mapped for a distance of more than 2 miles (pl. 3). This belt extends southwestward beyond the mapped area and widens appreciably. The second belt crops out in the southwest corner of the area and trends southward from Copper Creek for more than 4 miles to the south margin of the mapped area and beyond. The best exposures of the formation occur in the stream beds which cut through a representative section of the volcanic flows and tuffs in the southeast corner of the area.

In the southeastern belt the Bridle formation crops out in a homoclinal block, and the flows and interbedded sedimentary rocks strike northeast and dip steeply to the northwest. The tops of beds face northwest. Igneous rocks believed to have been intruded along faults bound this belt on the northwest and southeast. In the mapped area more than 3,000 feet of metamorphosed lava flows and interbedded tuff and other sedimentary rocks are exposed, but a much greater thickness is exposed in the unmapped area south of Bridle Creek.

[1] Anderson, C. A. and Creasey, S. C., Geology and ore deposits of the Jerome area, Yavapai County, Ariz.: [In preparation.]

In the southwestern belt the Bridle formation also forms a homoclinal block and the flows and tuff beds strike northeast and dip northwest at moderate to steep angles. Channeling and graded bedding indicate that the beds are overturned. This belt of the Bridle formation has been intruded by a variety of igneous rocks, in large part concordant with the volcanic flows, so that it is difficult to measure the thickness of the sequence. Rhyolite and alaskite porphyry were intruded along the northwest margin of this belt, and to the east the formation is cut off by the Mountain Spring fault, so neither its top nor its base is exposed. The conclusion that the Bridle formation is the oldest formation of the Yavapai series is not based on direct evidence but on an interpretation of characters of the Butte Falls tuff, as discussed on page 10.

Lava flows.—Many of the lava flows in the Bridle formation have recrystallized to massive dark-greenish-black rocks in which foliation is conspicuous only locally. Amygdules are rather common, particularly near the tops of the flows. In the southwestern belt they are composed of quartz or quartz and epidote, but in the southeastern belt amygdules are fewer and composed largely of calcite, which is leached at the surface. Pillow lavas were observed along the east branch of Alum Creek north of the Copper King mine and to a lesser extent in the hills north of Bridle Creek. The pillows average 1 by 2 by 3 feet in dimensions and have a fine-grained border. Most amygdules in the pillows are composed of epidote. Good flow structure is shown in some of the flows by oriented plagioclase phenocrysts. In spite of the metamorphism, the plagioclase phenocrysts and the amygdules are distorted only locally.

Thin sections of the typical massive lava flows show crystals of pleochroic hornblende, greenish-blue to yellow-green, in subparallel or completely unoriented arrangement. The hornblende crystals are separated by small interlocking phenocrysts of twinned or untwinned oligoclase or andesine. In some specimens, the original plagioclase phenocrysts are altered to zoisite. Clots of hornblende possibly indicate original mafic phenocrysts. Ilmenite presumably was an important original accessory mineral because in some thin sections where black opaque minerals are absent granular sphene is abundant. Accessory apatite and zircon are present. In some specimens, a relict intergranular texture is suggested; large plagioclase crystals, partly retaining albite twinning, are separated by small unoriented crystals of hornblende. Epidote in veinlets or as scattered granules is present locally. The mineral assemblage and presence of amygdules and pillows indicate original andesitic or basaltic lavas.

In the southwestern belt, there is more variation in mineral composition of the lava. Half a mile south of the Mammoth prospect the Bridle formation consists of flows of a conspicuously porphyritic lava containing partly recrystallized relict oligoclase phenocrysts, separated by green amphibole and alkalic feldspar and accessory ilmenite(?) and apatite. The original texture probably was porphyritic with an intergranular groundmass.

In the rest of the southwestern belt, the Bridle formation contains small brown biotite crystals that have formed at the expense of hornblende. Locally, some chlorite is intergrown with the biotite. In most places the mica flakes are in poorly defined parallel arrangement. Epidote is common, as aggregates of coarse crystals and as scattered granules. Untwinned albite or oligoclase crystals are separated by quartz. Quartz is present in lenses and streaks, particularly in some of the foliated facies. The amphiboles are usually absent from the quartz-rich rocks, but relict quartz amygdules prove that the rocks originally were lava flows.

The rocks mapped as Bridle formation may include some basic intrusive rock, such as diabase, that may be contemporaneous with the extrusion of the lava or related to diabase younger than the lava. Where diabase is in contact with the lava in the Bridle formation, subdivision of the two in mapping is difficult unless relict volcanic structures or relict diabasic textures are present.

Mixed rocks.—A belt of mixed rocks that crop out southwest of the Copper King mine is composed of amygdaloidal lava mixed with alaskite porphyry (pl. 3).

The mixed rocks contain conspicuous quartz amygdules, but the rocks are gray and streaked with light-colored bands, in contrast to the normal dark-greenish-black of the lavas in the Bridle formation. Locally, small reddish garnet crystals appear in the light-colored facies and also in clots of biotite. A few large randomly oriented green amphibole needles are present. Thin sections reveal that the mixed rocks consist largely of a microgranular aggregate of untwinned alkalic feldspar and quartz in which chlorite and biotite are irregularly distributed. A few clots of greenish-blue hornblende needles partly replaced by epidote, biotite, and chlorite are probably residuals from the original lava. Apatite is a conspicuous accessory mineral, appearing as coarse crystals in some specimens. The microgranular quartz and feldspar facies is similar to the border facies of the nearby alaskite porphyry intrusive masses and indicate that the amygdaloidal lava flows have been rather pervasively replaced by alaskitic material without destruction of the original amygdaloidal structure.

Spotted schist.—South and north of the Copper King mine, a belt of chlorite-biotite schist has been mapped separately as "spotted schist" (pl. 3). On surfaces essentially perpendicular to the poorly developed foliation the light-colored ellipsoids stand out in contrast to the darker host rock, particularly on weathered surfaces where the host rock is stained with iron oxide. The ellipsoids range in length from one-sixteenth of an inch to 2 inches, and their long axes are parallel to the foliation. Along some of the foliation planes, the light-colored material is essentially irregular and veinlike in pattern, but in many outcrops, the light-colored rock occurs as separate ellipsoids that can be broken from the host rock. Although these "spots" are not uniformly distributed throughout the area mapped as "spotted schist" they are sufficiently abundant and conspicuous to distinguish the rock as a cartographic unit. In some specimens the host rock consists of granular quartz and alkalic feldspar separated by chlorite and biotite with poor parallel structure; garnet is sporadic. The light-colored "spots" consist of microgranular quartz and subordinate alkalic feldspar and conspicuous accessory apatite. In most of the specimens, biotite is subordinate to the chlorite or entirely absent in the host rock, and the light-colored "spots" consist of microgranular quartz and abundant sericite. The sericite locally shows a parallel structure. The garnet is partly replaced by veinlets of sericite.

West of the Old Dick mine, outcrops of similar spotted schist (too small to be shown on pl. 3) occur in a zone bordering small masses of alaskite porphyry intrusive into chlorite schist. The change from chlorite schist to spotted schist is gradational. Relict amygdules indicated that the host rock was lava. North of the Copper King mine, relict bedding in the spotted schist indicates that tuffaceous sedimentary rocks were also host rocks.

The origin of these ellipsoids of light-colored rock is not definitely known, but the proximity of the "spotted" schist to the alaskite porphyry intrusive masses suggests a genetic relationship, particularly as the quartz-feldspar aggregates in the small ellipsoids are similar in texture and composition to the finer grained border facies of the alaskite porphyry. The quartz-sericite aggregates of other ellipsoids could have been produced by later metamorphism of the quartz-feldspar aggregates. Some orientation of the ellipsoids may have been caused by dynamic metamorphism, but the orientation of the many coarse biotite-chlorite crystals essentially at right angles to the foliation does not lend much support to this explanation. Probably, the light-colored material represents small-scale introduction of alaskitic material into tuffaceous sedimentary rocks or into foliated lava flows.

Clastic rocks.—The sedimentary rocks in the Bridle formation were predominantly deposited in water as shown by relict small-scale bedding and channeling. These sedimentary rocks have become schistose rocks in which chlorite and sericite are the chief foliate minerals. In some beds small reddish garnets are abundant. Thinly bedded tuffaceous sedimentary rocks exhibit the best developed foliation. Thin sections reveal considerable quartz in the bedded facies, and also ilmenite(?) and sphene. In one locality north of the Copper King mine, a 75-foot bed of agglomerate contains unsorted volcanic fragments and bombs.

Near the base and near the top of the section along Bridle Creek, layers of grayish-white massive to poorly schistose rhyolite tuff intercalated with basalt flows have been separated (pl. 3) from the rest of the Bridle formation. (See *brt* on pl. 3.) Relict sedimentary structures, such as bedding—locally graded—and channeling indicate that the bulk of these rocks were water-deposited. In the hand specimen, quartz and feldspar crystals are embedded in a finely crystalline base that is resolved under the microscope into a microgranular aggregate of quartz and untwinned alkalic feldspar containing streaks of minute flakes of chlorite, greenish to brown biotite, and sericite. The scattered larger feldspar crystals are albitic in composition and show good albite twinning. Eoidote is a minor accessory mineral. In some specimens the presence of small quartz veinlets essentially parallel to the poorly developed foliation is evidence of later silicification. The mineral composition, which suggests rhyolitic debris and relict sedimentary structures indicate water deposition, implying that these rocks were rhyolite tuffs. It is possible that some of the rocks of the more massive facies may have been flows or rocks intruded into the tuffs, although no evidence for this inference was found. A narrow band of quartz-sericite schist on the west side of the Mountain Spring fault has been tentatively correlated with the rhyolite tuff in the Bridle Creek area. The quartz-sericite schist consists of angular quartz grains and aggregates of albite crystals embedded in a matrix of minute quartz grains and abundant sericite flakes that are substantially parallel.

Altered facies.—The Bridle formation locally is altered to a quartz-epidote rock that usually occurs in small lenses essentially parallel to the structure of the rest of the formation. In the southeastern belt, brown massive garnet is common in these altered masses, some of which are 100 feet wide and several hundred feet long. Presumably these have been formed by later hydrothermal alteration, possibly after the widespread invasion of granite.

Origin.—The Bridle formation accumulated as a series of andesitic and (or) basaltic lava flows and intercalated water-deposited tuffaceous and terrigenous sediments. The occurrence of the pillow lavas indicates that some of the flows were extruded under water, and possibly the entire sequence of flows and tuffs accumulated under water. This conclusion is based on the recognition of bedding in the tuff.

BUTTE FALLS TUFF

The Butte Falls tuff is exposed for more than a mile along Boulder Creek in the vicinity of Butte Falls, for which these rocks have been named. Smaller outcrops are exposed to the west along the steep slope of Bozarth Mesa. Other exposures are east of Lucy Peak, south of Mountain Spring, and southeast and east of Bagdad along Maroney Gulch.

Along Boulder Creek the tuff strikes north and dips steeply eastward, and more than 2,000 feet of the beds are exposed in continuous section. If, as seems probable, the tuff continues under the lava cover from Boulder Creek westward to an isolated exposure, its total thickness is more than 2,500 feet. The other outcrops expose much thinner sections, for the base of the tuff is cut off by faults near Lucy Peak and near Mountain Spring, and by younger intrusive rocks along Maroney Gulch.

Graded bedding and channeling prove that the tops of the beds face east along Boulder Creek, and the zone of gradation from the Butte Falls tuff to the younger Hillside mica schist is well exposed. The younger age of the mica schist is indicated, though less clearly, along Maroney Gulch. East of Lucy Peak, the tuff is bounded by the Mountain Spring fault to the east and south, and by the younger quartz monzonite to the north. On the west the tuff is bounded by the King Peak rhyolite and younger rhyolite that were intruded along a fault between the tuff and the Bridle formation. Graded bedding and channeling indicate that here these beds of tuff dip westward and are overturned. Near Mountain Spring, faults separate the Butte Falls tuff from the younger Hillside mica schist and Dick rhyolite.

The relationship of neither the Butte Falls tuff nor the Hillside mica schist to the Bridle formation is revealed in the area mapped. Two facts, however, lead to the inference that the Butte Falls tuff represents tuffs and tuffaceous sediments that accumulated after the outpouring of the mafic lava of the Bridle formation: (1) the quartz-sericite schist (rhyolite tuff) that occurs in the Butte Falls tuff near its base west of Boulder Creek has some petrographic similarities to the rhyolite tuff intercalated in the upper part of the Bridle formation along Bridle Creek; (2) some of the tuffaceous beds of the Butte Falls contain much biotite that may represent metamorphosed andesitic or basaltic debris derived from the Bridle formation. If it is assumed that the two units of rhyolite tuff are about the same general age and that the biotite represents debris from the Bridle formation, it can be inferred that the Butte Falls tuff is younger than the Bridle formation. It should be emphasized, however, that additional work in the region may uncover evidence contrary to this inference.

Several kinds of rocks have been grouped under the Butte Falls tuff, including quartz-sericite schist, quartz-feldspar-biotite schist, and grayish-white, gray, and purple slate.

In the northern part of the area, west of Boulder Creek, quartz-sericite schist is exposed near the base of the section and contains abundant coarse irregular quartz grains in a sericitic matrix. Original bedding is rarely preserved but a few conglomeratic beds containing quartz and jasper pebbles suggest the sedimentary character of the original rock. Thin sections of the quartz-sericite schist reveal scattered microperthite crystals subordinate to the conspicuous angular quartz grains, both embedded in a matrix of abundant sericite, finely granular quartz, and alkalic feldspar. Foliation is pronounced, owing to the parallel arrangement of the sericite.

This quartz-sericite schist grades upward into gray poorly foliated biotite-quartz-feldspar schist, well exposed west of Butte Falls. Small angular quartz and feldspar grains are fairly common, and the biotite is abundant in very small flakes. Some beds are massive, 20 to 30 feet thick, but most of them are a fraction of an inch to several feet thick. In the thinner beds graded bedding, channeling, and crossbedding aids in the determining of the direction that the beds face. Examination under the microscope revealed the feldspar to be albite clouded with sericite flakes and epidote granules. The matrix is composed of a microcrystalline aggregate of alkalic feldspar and subordinate quartz, epidote granules, and greenish biotite. Some of the biotite occurs in streaks of parallel flakes. Accessory apatite is common. This gray biotite-quartz-feldspar schist also constitutes the bulk of the Butte Falls tuff in the southern part of the area near Lucy Peak and Mountain Spring.

Interbeds of gray or purple slate are as much as 10 feet thick. East of Butte Falls, grayish-white sericite slate, 150 feet thick, is interbedded with the biotite-quartz-feldspar schist. Few quartz grains are visible in the slate, which presumably represents original fine clastic sedimentary rocks such as shale or tuffaceous shale. Minor folds are limited to the slate beds.

North of Butte Creek along the east canyon wall of Boulder Creek, quartz-muscovite schist containing abundant quartz grains of uniform size is interbedded with quartz-muscovite-biotite schist in which the quartz grains are scattered, irregular in shape, and of variable size. The quartz-muscovite-biotite schist is assumed to represent tuffaceous beds, whereas the quartz-muscovite-schist represents sediments richer in nonvolcanic detritus.

Along Boulder Creek streaks of chlorite and biotite schist, 6 to 12 inches wide, are partly concordant with and partly discordant to the bedding. They are also found in the younger Hillside mica schist and presumably represent metamorphosed basic dikes and sills, possibly of a diabasic rock. A thin section shows excellent foliation resulting from the parallel orientation of minute biotite flakes separated by a fine mosaic of alkalic feldspar grains, epidote granules, and calcite lenses.

In the vicinity of Maroney Gulch, the Butte Falls tuff is grayish white and massive, and the resemblance to the gray Butte Falls tuff is noteworthy only in the eastern exposures. However, on weathered surfaces, an original clastic texture is suggested by scattered irregular quartz grains, reminiscent of the Butte Falls tuff as exposed along Boulder Creek. The microscope reveals that the gray massive rock contains scattered irregular quartz grains separated by a mat of sericite flakes associated with a few clots of greenish-brown biotite, and accessory apatite, magnetite(?), and blue tourmaline. Some of the Butte Falls tuff in the vicinity of Maroney Gulch is so intimately intruded by Lawler Peak granite that a complete distinction cannot be made on plate 3, and some areas are indicated as mixed Butte Falls tuff and Lawler Peak granite. Probably the granite has caused recrystallization of the tuff in this area, with a resultant loss in foliation. However, some parts of this massive facies might represent intrusive masses of younger rhyolite, although only the massive character suggests this possibility.

Near Butte Creek a number of small quartz-tourmaline veins cut the Butte Falls tuff. Tourmaline schist has developed for several inches along the vein margins.

The Butte Falls tuff accumulated as a series of water-deposited sediments of volcanic derivation, although some of the massive beds may represent subaerial accumulation of pyroclastic material. The source material was probably juvenile or reworked rhyolitic debris mixed with some andesitic or basaltic detritus, possibly derived from the Bridle formation. Near the top of the section, more and more nonvolcanic sediment was added until the rocks were entirely of terrigenous source. Later these rocks were metamorphosed to slate and schist.

HILLSIDE MICA SCHIST

The most complete section of the Hillside mica schist is well exposed along Boulder Creek in the vicinity of the Hillside mine, for which this formation of the Yavapai series has been named. Another incomplete section is also exposed along Butte Creek near the Comstock-Dexter mine, and small outcrops are found in Copper Creek between Copper Creek Mesa and Sanders Mesa. The Hillside mica schist also occurs extensively in the south-central and southeastern part of the area and southeast of Mountain Spring.

In all parts of the area mapped, the top of the Hillside mica schist is cut by intrusive igneous rocks, particularly the Lawler Peak granite, so that no information is available concerning the maximum thickness of the formation. The most complete section of the Hillside mica schist is exposed along Boulder Creek, and the strikes and dips are more uniform there than elsewhere, but owing to considerable minor folding it is difficult to measure the thickness with any degree of accuracy. A minimum thickness of 3,000 to 4,000 feet of schist is probably present although the upper limit is not exposed. Elsewhere in the Bagdad area, except southeast of Mountain Spring, the mica schist has been intensely deformed into many small folds of varying amplitude, and the outcrops are discontinuous and separated by intrusive rocks. Therefore the thickness is impossible to determine.

The Hillside mica schist includes muscovite schist, quartz-muscovite schist, and muscovite quartzite. Except in the muscovite schist, bedding is in general, easily recognized. Near the Lawler Peak granite, the muscovite flakes are coarse, as much as 5 millimeters in size, and are only partly oriented, parallel to the bedding. Along Copper Creek, north of Bagdad, and in the southeast corner of the area, fibrous yellowish-gray sillimanite needles in sheaflike groups are roughly parallel to the bedding. Thin sections reveal minute sillimanite needles in some of the coarser muscovite crystals and a small amount of biotite is intergrown with the muscovite. Accessory minerals are apatite, zircon, magnetite (?), and sphene.

In the Butte Creek section, the basal members are dominantly muscovite schist and grade upward into a sequence of alternating layers of muscovite schist, quartz-muscovite schist and mica quartzite. Elsewhere it is difficult to recognize any order of sequence of these rock types.

Tourmaline schist is locally present adjacent to narrow quartz-tourmaline veins and unoriented coarse muscovite forms borders 2 inches wide along both margins of some quartz veins.

The Hillside mica schist was originally a series of shale, sandy shale, and impure sandstone that accumulated in a basin after a period of considerable volcanic activity.

INTRUSIVE ROCKS

KING PEAK RHYOLITE

In the southwestern part of the area intrusive rhyolite is well exposed on King Peak, for which this rock has been named. The mass of rhyolite extends about 4,000 feet to the northwest of King Peak and about 1 mile north-northeast toward Copper Creek. Other masses crop out to the northwest and southeast of King Peak and along Bridle Creek.

The mass of King Peak rhyolite exposed west of Niagara Creek (pl. 3) is essentially concordant with the southwestern belt of the Bridle formation, but ample evidence proves that the rhyolite is intrusive. Inclusions of volcanic material from the Bridle formation are locally present in the rhyolite, and along Niagara Creek, alternating layers of rhyolite and Bridle formation averaging 20 feet in width are parallel to the bedding structures of the Bridle formation, suggesting bed-by-bed intrusion by the rhyolite.

The northwest-trending mass of rhyolite exposed near the Copper King mine appears to have been intruded along a fault, as shown by the offset of the spotted-schist unit of the Bridle formation on the north side of the rhyolite mass. Because the spotted schist is probably of secondary origin, this evidence is not conclusive, but the distribution of pillow and massive-lava flows north and south of the rhyolite mass also indicates a displacement along the zone occupied by the rhyolite. The thin belt of rhyolite from King to Lucy Peaks is probably also located in part along an old fault, for the north end of the belt separates the Bridle formation from the Butte Falls tuff, which are structurally discordant in this locality.

The outcrop pattern of the King Peak rhyolite suggests intrusion after the deformation of the Yavapai series; the location of two masses along old faults is further proof of this conclusion.

The King Peak rhyolite is the oldest intrusive rock in the Bagdad area, if our interpretation that it is older than the Dick rhyolite is correct. Possibly the Dick and King Peak rhyolites are approximately of the same age. The gabbro and alaskite porphyry are intrusive into the King Peak rhyolite.

The King Peak rhyolite is a fine-grained nonporphyritic rock containing quartz and feldspar. It is generally massive and foliation is rare. The rock is white and sugary in appearance on unweathered surfaces, but the outcrops typically are tan in the western belt near Niagara Creek. The eastern exposures are brown, owning to the oxidation of pyrite contained in small quartz veinlets. In the vicinity of King Peak the rock is a little darker, because of minute dark-green hornblende crystals. Along Bridle Creek the rhyolite outcrops are grayish white.

Thin sections reveal a microgranular texture. Quartz is slightly in excess of interstitial untwinned alkalic feldspar and has an index of refraction less than that of balsam. Under crossed nicols, the quartz crystals show strain shadows and some sericite has formed in the feldspar. The darker colored rhyolite contains scattered needles of dark-green hornblende, similar to the amphibole in the Bridle formation, that probably are mafic-mineral xenocrysts derived from the Bridle formation.

DICK RHYOLITE

In the south-central part of the area, a large mass of Dick rhyolite is well exposed on Dick Peak, for which this rock is named. This mass, more than 2,000 feet wide, has been mapped for a distance of a mile, and extends southward beyond the mapped area. A small mass crops out east of King Peak and forms a northward-trending series of crags.

The Dick rhyolite intrudes the Bridle formation and the Butte Falls tuff in the region of Dick and King Peaks. The field evidence is inconclusive, but the pattern of the outcrops indicates that it also intrudes the King Peak rhyolite east of King Peak. The Dick rhyolite is intruded by the gabbro east of King Peak.

The Dick rhyolite resembles the King Peak rhyolite in a general way, the only distinction is the presence in the Dick rhyolite of quartz phenocrysts that are embedded in a finely crystalline groundmass resembling the texture of the King Peak rhyolite. Thin sections reveal the groundmass as a microgranular aggregate of quartz and low-index alkalic feldspar containing scattered epidote granules and sericite flakes. Locally the Dick rhyolite is foliated, becoming a quartz-sericite schist. South of Dick Peak, the Dick rhyolite is darker, owing to the presence of hornblende needles that presumably are xenocrysts derived from the Bridle formation, as in the King Peak rhyolite. Some pyrite occurs in quartz veinlets in the outcrops near Mountain Spring fault, and the exposures are stained brown from the oxidized pyrite.

GABBRO AND RELATED ROCKS

Gabbro and related rocks, anorthosite, quartz diorite, diabase and mixed granite-gabbro, are widely distributed in the southern half of the mapped area. In the western part of this area a large mass of gabbro, cut by anorthosite—found only in this mass—crops out south of Centipede Mesa in a band 3,000 to 4,000 wide; including the outcrops in Boulder Canyon north of Centipede Mesa, this mass is more than 4 miles long. To the north, the gabbro mass is buried under Bozarth Mesa except for small exposures on the east wall of the mesa. Several dikes of gabbro and diabase, 100 to 300 feet wide, occur in a zone extending southwestward from Lucy Peak to near Grayback Mountain. East of the Mountain Spring fault a large mass of mixed granite and gabbro is exposed in an area a mile long and more than half a mile wide. Gabbro, quartz diorite, and mixed granite and gabbro crop out east of Bagdad along the headwaters of Maroney Gulch to south of Nelson Mesa. These masses are irregularly shaped and of different sizes. Small outcrops of gabbro occur north of Sanders Mesa along Copper Creek and north of Copper Creek Mesa near Butte Creek, and one dike crops out west of the Comstock-Dexter mine. The quartz diorite masses are small, with the exception of one outcrop along Maroney Gulch which is 4,500 feet long.

The gabbro intrudes the Bridle formation, Hillside mica schist, King Peak and Dick rhyolites, and is intruded by alaskite porphyry and the Lawler Peak and Cheney Gulch granites. The evidence indicates that granodiorite gneiss also is younger than the gabbro. South of Nelson Mesa the gabbro is intruded by many dikes and masses of aplite-pegmatite related to the Lawler Peak granite. The anorthosite dikes intrude only the large western gabbro mass. The quartz diorite, assumed to be related to the gabbro because of spatial relations and petrographic similarity, intrudes only the Hillside mica schist, and is intruded by the Lawler Peak granite. The diabase intrusions are not all of the same age; most of the diabase dikes apparently are related to the gabbro, representing smaller intrusions in the same general zone. Some diabase dikes intrude alaskite porphyry and are younger than the gabbro.

The gabbro masses west of the Mountain Spring fault are essentially concordant with the structure of the Bridle formation and can be considered to be sill-like in form. East of the Mountain Spring fault where the bedding of the Hillside mica schist is contorted, the irregularly shaped gabbro masses are no doubt related in part to the structure of the schist. The gabbro mass along Bridle Creek was injected along a fault separating the Bridle formation from the Hillside mica schist; this mass widens appreciably to the north toward the Nelson Mesa. In the southeast corner of the area diabase was intruded along a fault on the southeast border of the Bridle formation, which separated the formation from the Hillside mica schist.

Gabbro.—The typical gabbro of the area is dark and the grains range in size from fine to coarse. Black hornblende, with or without a core of augite, and plagioclase are the chief minerals, but interstitial quartz is present in many specimens. Biotite is a common accessory mineral, particularly in the east near the Lawler Peak granite, locally occurring as unoriented crystals as much as three-eighths of an inch in diameter. In this biotite-rich facies, slender needles of apatite and grains of sphene are conspicuous accessory minerals, possibly produced in part by the intrusion of the Lawler Peak granite. Magnetite and ilmenite are common accessory minerals, particularly in the western exposures.

Most of the gabbro is foliated, resulting in a gneissoid structure, and the hornblende crystals commonly have a linear arrangement in the plane of foliation. Along the eastern margin of the mass, west of the Comstock-Dexter mine, the gabbro is schistose, and north and south of Centipede Mesa narrow lenses of schistose gabbro are 20 to 30 feet wide but of no great length. Some small outcrops of talc schist presumably represent original magnesia-rich facies of the gabbro.

The large mass south of Centipede Mesa is essentially a multiple intrusive with several facies mutually intrusive. Fine-grained gabbro is both older and younger than coarse-grained gabbro, which locally is almost pegmatitic, for it contains hornblende crystals as much as 1 inch long. Along Copper Creek, north of Sanders Mesa, mafic gabbro has been brecciated and cemented by felsic gabbro.

Thin sections reveal that there has been little recrystallization of some of the gabbro, for pale-gray diopsidic augite is only slightly replaced by pale-green amphibole (actinolite(?)) that is bluish green at the edge (hornblende). Associated labradorite is clear and unaltered. Generally, the gabbro contains augite cores with greenish-blue hornblende rims, and also separate hornblende crystals, and the plagioclase ranges from oligoclase to andesine in composition; epidote granules may or may not be present. Brown biotite may be associated with some of the hornblende and a few quartz grains interstitial to the feldspar are locally present. Many specimens of gabbro consist of bluish-green hornblende and albite clouded with epidote, and containing biotite partly replaced by chlorite. The schistose gabbro in part consists of bands of light-green amphibole in parallel orientation separated by bands of granular oligoclase and quartz; considerable epidote and some biotite are partly in random orientation attached to the amphibole. Other schistose specimens contain chlorite in place of biotite and albite in place of oligoclase. Apatite and magnetite-ilmenite are common accessory minerals in all the gabbro; sphene is more sporadic in its distribution.

Anorthosite.—The anorthosite is a white to light-gray rock, the color varies with the content of mafic minerals. Some of the specimens contain more than 10 percent of mafic minerals and properly are gabbroic anorthosites (Buddington, 1939, p. 19). The anorthosite is a coarse-grained hypidimorphic rock, and black hornblende, the chief mafic mineral, is sporadic in distribution. The feldspar in the anorthosite is calcic andesine, resembling other anorthosite masses (Buddington, 1939, p. 31). A little epidote is present, possibly indicating a more calcic feldspar originally. Some of the plagioclase, however, is completely altered to sericite and zoisite with traces of chlorite and green hornblende.

The anorthosite intrudes the more mafic gabbro which is well exposed at the ends of the anorthosite dikes, but the anorthosite is, in turn, intruded by the finer grained facies of the gabbro. The anorthosite dikes have a northeast trend parallel to the foliation in the gabbro except for one dike in Boulder Canyon that has a northwest trend. The east-west gap in the anorthosite dikes in Mulholland Basin (pl. 3) is conspicuous but no plausible explanation can be offered. Although the gabbro is foliated, the anorthosite rarely shows this structure, presumably because of the paucity of mafic minerals.

Quartz diorite.—The quartz diorite is lighter in color than the gabbro, and quartz is a conspicuous constituent in addition to the plagioclase, biotite, and hornblende. Granular sphene is a common accessory mineral, visible with the hand lens. The texture is granular, hypidiomorphic, and some facies have a gneissic structure. The field studies indicate that the quartz diorite was a differentiate from the gabbro, as some of the contacts are transitional and the quartz diorite is spatially related to the gabbro. Locally, some orthoclase is present, but this mineral was probably introduced by the Lawler Peak granite. A possibility also exists that some of the quartz was added from the Lawler Peak granite, and that some of the outcrops mapped as quartz diorite are those of mixed rocks.

The plagioclase ranges in composition from oligoclase to andesine, and some poikilitic orthoclase is present. The quartz has recrystallized to aggregates and shows some strain shadows. The chief accessory minerals are a brown biotite, and a deep-green hornblende, and the minor accessory minerals include: sphene, in large granules; abundant apatite needles, and a few zircon prisms. Granules of magnetite are common particularly where adjacent to biotite.

Diabase.—The diabase is a fine-grained dark-colored rock, composed of plagioclase and hornblende. Generally the texture is fine-grained granular, and only local areas furnish specimens having relict diabasic texture that yield clues as to the original character of the rock. All fine-grained granular dark-colored dike rocks were mapped as diabase; as a result, some fine-grained gabbro may be included. Although the mapping of diabase north of Grayback Mountain outlines dikelike forms, the detailed examination of some of the contacts reveals that, here the diabase has been intruded by the alaskite porphyry, indicating that the dikelike bodies are essentially inclusions. Elsewhere, as along Alum Gulch, evidence indicates that some of the diabase is intrusive into the alaskite porphyry.

In many thin sections, the relict diabasic texture is well preserved, and euhedral crystals, oligoclase to andesine in composition, possess excellent albite twinning; they are separated by anhedral bluish-green hornblende that occurs as crystal aggregates or as individual large crystals. Magnetite(?) crystals are conspicuous, and apatite is a minor accessory mineral. In some sections, quartz grains are interstitial to the feldspar. The granular diabase consists of equidimensional hornblende separated by sericitized oligoclase and by quartz cut by epidote veinlets. Sphene is locally developed from ilmenite(?).

Magnetite-ilmenite.—Magnetite-ilmenite dikes occur in the western gabbro mass. South of Centipede Mesa, they are 1 to 3 feet wide and 20 to 50 feet long, but along Boulder Creek they are 20 feet wide and several hundred feet long. The dikes both crosscut and parallel the foliation of the gabbro. These dikes have been described by Ball and Broderick (1919), who suggested that the magnetite-ilmenite bodies are essentially magnetite-rich facies of the gabbro. They gave the following chemical analyses:

Fe	60. 09	62. 02	60. 35
Ti	9. 80	8. 20	8. 40
Mn	Tr	Tr	Tr

A microscopic examination of a polished surface shows that the ilmenite and magnetite are in equidimensional grains; magnetite is in excess of the ilmenite. The magnetite contains an intergrowth of specularite, particularly at the crystal boundaries, but only a trace of specularite is intergrown with the ilmenite.

A program of trenching and sampling of these magnetite-ilmenite dikes was started in 1952, and it is reported that the widths of these dikes are greater than observed in the natural outcrops, and that the percent of titanium is higher than shown in the preceding analyses.

Mixed gabbro and Lawler Peak granite.—The area south of the mesas and east of the Mountain Spring fault contains masses of gabbro and locally, some quartz diorite that are so intimately associated with the younger Lawler Peak granite that it was impossible to differentiate the rocks on the map, owing to the scale used. Not only is the gabbro ramified by narrow dikes of granite, but it contains new minerals derived from the granite, particularly large orthoclase porphyroblasts, commonly poikilitically enclosing small unoriented hornblende crystals. The gabbro is usually lighter in color, as the result of this addition of new minerals, which probably included some quartz, but because the gabbro also is locally quartz-bearing, it is difficult to distinguish secondary from primary quartz. Biotite is usually well developed in the mixed rocks, and apatite and sphene are easily recognized. Albite and epidote granules are locally present in place of the more calcic plagioclase.

ALASKITE PORPHYRY AND RELATED ROCKS

Alaskite porphyry and related rocks that include contaminated alaskite porphyry, alaskite, and mixed alaskite and gabbro are limited to the western half of the area. A small area of mixed alaskite porphyry and Lawler Peak granite is exposed along Copper Creek north of Sanders Mesa.

The alaskite porphyry crops out in three wide bands that strike northeast: One band extends from Boulder Creek to Grayback Mountain, a distance of 4 miles, and ranges in width from 1,000 to 3,000 feet. Another band extends from the junction of Alum and Copper Creeks southwestward for a mile and has a maximum width of 3,000 feet. A third band crops out in a wedge-shaped area northeast of Grayback Mountain, and becomes wider to the southwest beneath the rhyolite tuff on Grayback Mountain. A narrow band is exposed also on the east-facing slope below Bozarth Mesa. The contaminated alaskite porphyry occurs in a narrow band 1½ miles long west of Niagara Creek and in a broader band, 2 miles long between the two masses of alaskite porphyry that extend to Grayback Mountain, and in a third band over a mile long to the east of Grayback Mountain.

Outcrops of alaskite, and mixed alaskite and gabbro are largely confined to the western band of alaskite porphyry along the gabbro contact; one area is 1½ miles north of Grayback Mountain and the other is along Boulder Creek above its junction with Copper Creek. Small outcrops of alaskite occur in the gabbro south of Centipede Mesa.

The alaskite porphyry intrudes the Bridle formation, the King Peak rhyolite, and the gabbro, and it in turn is intruded by some of the diabase dikes, the Lawler Peak granite, and the quartz monzonite and related dike rocks of Late Cretaceous or early Tertiary age. The Grayback Mountain tuff was deposited on an irregular erosion surface formed on the alaskite porphyry. The alaskite porphyry masses are essentially parallel to the structure of the Bridle formation. The mass having the wedge-shaped outcrop may have exerted some force along the northern contact, pushing the Bridle formation to the north, and causing the lava flows to strike eastward to the north of Grayback Mountain, whereas the normal northeast strikes persist on the east side of the mountain. In contrast, the northeast trend of the contaminated alaskite porphyry and mixed Bridle formation and alaskite porphyry suggest a replacement of the lava flows without any strong accompanying force.

Alaskite porphyry.—Two facies of the alaskite porphyry are differentiated on plate 3; one has a microcrystalline groundmass and the other has a finely phanerocrystalline groundmass. The microcrystalline groundmass facies is gray to white. Quartz phenocrysts are widely distributed, and in the dikes and smaller masses they may be the only visible phenocrysts. In the larger masses feldspar phenocrysts consist of twinned albite and orthoclase, and, locally, of microcline. The microcrystalline groundmass is resolved under the microscope into aggregates of quartz and alkalic feldspar; the latter includes some twinned albite. The texture of the groundmass is not uniform, consisting in part of irregular-sutured intergrowths of quartz and feldspar, and in part of micrographic intergrowths of quartz in feldspar, commonly in a radiating structure. In some thin sections the groundmass minerals are very minute and exhibit "patchy" polarization. Sericite flakes and clusters of epidote granules appear locally, and in some specimens that are dark gray, small flakes of biotite are present in the groundmass, presumably representing some contamination from the Bridle formation. Apatite is a rare accessory mineral and sphene occurs sporadically as clusters of granules. Locally, the microcrystalline groundmass facies of alaskite porphyry is silicified, and only the quartz phenocrysts remain as relicts of the original texture. Some calcite, epidote, and sericite are associated with the introduced quartz.

Some parts of the microcrystalline facies of the alaskite porphyry could be differentiated from the Dick rhyolite only with difficulty. One useful criterion is the micrographic intergrowth of quartz and feldspar that is characteristic of this facies of the alaskite porphyry and is absent in the Dick rhyolite. In some outcrops, the micrographic texture in the microcrystalline facies of the alaskite porphyry could be recognized by use of a hand lens, but in others microscopic examination of thin sections were required to differentiate the facies. The distribution of the microcrystalline facies of alaskite porphyry along the margins of the finely crystalline facies indicates that the microcrystalline facies represent a chilled phase of the alaskitic magma, possibly the first intrusions in the sequence. The transition zone from the microcrystalline to the finely crystalline phase is rather narrow, rarely more than 30 feet in width.

The finely crystalline groundmass of alaskite porphyry is gray to pink, except for the exposures along Alum Gulch where outcrops have a reddish-brown coating of iron oxide, derived by oxidation of disseminated pyrite related to the younger quartz monzonite. The quartz and feldspar phenocrysts are larger than those in the microcrystalline facies and the minerals in the groundmass as well as the common micrographic texture can be recognized with a hand lens. Thin sections reveal that the coarse irregular quartz phenocrysts have been recrystallized to aggregates and many of the crystals show strain shadows. The feldspar phenocrysts include albite having fine-twinning lamellae and orthoclase or, locally, microcline-perthite. The groundmass consists of a sutured aggregate of quartz and alkalic feldspar, and some albite twinning is recognizable. The texture of the groundmass in places is microseriate, some crystals are almost as large as phenocrysts. Micrographic texture is common, and the intergrown quartz in the groundmass feldspar host radiates outward from adjacent feldspar phenocrysts. Epidote and sericite are rare, except locally, where they have been formed by later hydrothermal action. A few specimens contain stringers of bluish-green hornblende and scattered flakes of biotite probably derived from the Bridle formation.

Locally the alaskite porphyry is slightly foliated in zones as much as 10 feet wide; sericite flakes appear along the foliation planes and the phenocrysts are crushed. Elsewhere, the only sign of metamorphism is the recrystallization of the quartz phenocrysts.

Contaminated alaskite phorphyry.—Much of the contaminated alaskite porphyry is a light-colored foliated quartz-feldspar rock containing parallel flakes of biotite that weather to a buff color. Thin sections reveal relicts of the porphyritic texture, but much of the rock is composed of streaks of granulated quartz and untwinned alkalic feldspar. The brownish-green biotite flakes, partly replaced by chlorite, are essentially parallel to the streaks of granulated quartz and feldspar. Locally, minute needles of actinolite occur and are also parallel to the biotite. Sericite is abundant in some thin sections, but generally it occurs in minor amounts. Granules of epidote and sphene and stubby prisms of blue tourmaline occur sporadically. Apatite and magnetite(?) are conspicuous minor accessory minerals. Locally, unoriented aggregates of long needles of actinolite are present, and at places they contain some red garnet. The microscope reveals partial alteration of the actinolite to chlorite. Some layers of the contaminated rock contain fragments of the Bridle formation as much as 2 inches long, recrystallized to biotite or hornblende aggregates with no marked foliation. In places the contaminated alaskite porphyry has little or no foliation and possesses a porphyritic texture in which the microcrystalline groundmass contains unoriented crystals of biotite, chlorite, and epidote.

A facies of the contaminated alaskite porphyry occurs west of the Copper King mine. It has a brecciated appearance and has angular fragments of alaskite porphyry as much as an inch across in a microcrystalline greenish-gray matrix of contaminated alaskite porphyry rich in minute unoriented needles of actinolite. Probably the first intrusions of alaskite porphyry were relatively free of foreign material and formed a rock that was brecciated; later this rock was healed by magma containing much assimilated rock material from the Bridle formation.

The distribution of most of the contaminated alaskite porphyry indicates that the chief source of the assimilated material was the Bridle formation. It might be questioned that all the amphibole and the biotite were so derived, but the complete absence of these minerals in the central parts of the alaskite porphyry masses suggests a foreign source. Furthermore, neither of these minerals appear as phenocrysts, nor did the biotite grow in book form—the typical habit where biotite is a primary constituent of an igneous rock. The amphibole and biotite are not uniform in their distribution, but form clots and streaks. West of Niagara Creek, the contaminated alaskite porphyry contains scattered inclusions of gabbro, which suggests that the gabbro was the source of the mafic material. Because the mineralogic composition of the gabbro is similar to that of the Bridle formation, the composition of the contaminated rock would be the same regardless of the source of the mafic material.

Some types of rock of the Bridle formation were favorable sources of assimilated material in the alaskite porphyry; along Mammoth Wash the band of black porphyritic lava shows little change, but to the east the amygdaloidal lavas were partly soaked by alaskitic material or were completely resorbed to form contaminated alaskite porphyry. Again, tabular bodies of diabase north of Grayback Mountain have a dikelike form, but at some contacts small dikes of contaminated alaskite porphryy intrude the diabase, suggesting that the diabase was more resistant than the lava flows to resorption by the alaskite magma.

The origin of random orientation of the long actinolite needles presents a problem, because most of the contaminated alaskite porphyry is foliated. Possibly the actinolite formed after dynamic metamorphism caused the foliation, but because local masses of contaminated alaskite porphyry show no obvious foliation, the hornblende and garnet in these masses may have formed at the time of alaskitic intrusion and escaped later shearing during dynamic metamorphism.

Alaskite.—West of the Mammoth prospect along the gabbro-alaskite porphyry contact, granular alaskite crops out in masses large enough to be mapped (pl. 3). The alaskite is medium to coarse-grained hypidiomorphic granular in texture, and composed of irregular grains of smoky quartz and yellowish-gray feldspar. The book-like habit of the rare biotite crystals suggests they are primary, but they are too rare to warrant the use of the term "granite" for this rock. Thin sections reveal that the quartz crystals have recrystallized to granular aggregates and that the coarser grains show strain shadows. The feldspar consists of albite and orthoclase, locally microcline, in about equal proportions. Magnetite(?) and epidote are accessory minerals.

The zone of transition from granular alaskite to alaskite porphyry having a finely crystalline groundmass is less than 20 feet wide but no well-defined intrusive contacts were noted. However to the north of Mammoth Wash near the gabbro contact, narrow dikes of alaskite were found intrusive into the alaskite porphyry.

Mixed alaskite and gabbro.—The rock mapped as mixed alaskite and gabbro consists of two facies. One, an equigranular rock, composed of quartz, feldspar, and hornblende, is similar in thin section to the normal alaskite except for the presence of bluish-green hornblende as needles and as larger crystals interstitial to the quartz and feldspar. Some of the albite crystals have more calcic cores whereas others are heavily clouded with epidote granules. Sphene is an important accessory mineral. This facies makes up the bulk of the rock.

The other facies is an intrusive breccia composed of black fragments of gabbro in a matrix of granular alaskite. The gabbro fragments have recrystallized to fine-grained hornblende-rich aggregates. In general, the fragments are platy in form, 1 to 2 inches wide, 6 to 12 inches long, and as much as 2 inches apart in the hornblende-bearing alaskite. In places, the platy fragments of gabbro are oriented horizontally. Some fragments of gabbro are equidimensional and as much as 2 feet in size.

In some of the alaskite-gabbro breccia, the alaskite matrix is evenly granular at the margin of the fragments of gabbro, but in the center between the fragments of gabbro the texture is pegmatitic. This suggests that volatile material was becoming increasingly concentrated during the closing stages of the intrusions of alaskite and alaskite porphyry and this would account for the evenly granular texture of the last intrusion of alaskite, but no adequate explanation can be offered as to why these granular intrusives, rich in volatile material, are limited to the contact of the alaskite porphyry and gabbro.

Mixed alaskite porphyry and Lawler Peak granite.—The mixed alaskite porphyry and Lawler Peak granite exposed along Copper Creek north of Sanders Mesa, consists of the finely crystalline groundmass facies of the porphyry and carries scattered large porphyroblasts of orthoclase and some introduced crystals of muscovite. Thin sections show some coarsening of the texture of the groundmass, and the crystal boundaries are more regular than in the typical alaskite porphyry. Part of the mapped area is composed almost entirely of Lawler Peak granite containing scattered inclusions of the coarse orthoclase-bearing alaskite porphyry. This mixed rock has been fractured and narrow quartz-pyrite veins have been introduced. Some outcrops are stained brown from the oxidation of the pyrite. Presumably the quartz-pyrite veins are genetically related to the quartz monzonite intrusions of much later date.

GRANODIORITE GNEISS

West and south of the Hillside mine on the east side of Boulder Creek, the granodiorite gneiss crops out in two masses more than 3,000 feet long. Along Butte Creek, in the Hillside mica schist near the Lawler Peak granite, many small dikes of granodiorite gneiss are exposed, too small to be shown on plate 3. South of Sanders Mesa the largest masses of the granodiorite gneiss crop out as bands essentially concordant to the structure of the mica schist; one band is a mile long and 500 feet wide, but the others are smaller. A few small bodies occur in the Bridle formation north and south of Bridle Creek. Granodiorite gneiss mixed with Lawler Peak granite crops out south of Sanders Mesa, and in the southeast corner of the area.

The granodiorite gneiss definitely intrudes the rocks of the Yavapai series, locally in a bed-by-bed arrangement, and in turn it is intruded by the Lawler Peak granite. It is not found in contact with the King Peak and Dick rhyolites nor with the alaskite porphyry. The evidence for the age relationship of the granodiorite gneiss the gabbro is not entirely convincing, but dikes of the granodiorite gneiss apparently cut the gabbro. South of Sanders Mesa the gneiss is slightly foliated and more porphyritic near the gabbro contact, in contrast to its usual granular texture. North of Bridle Creek gabbro dikes appeared to be present in the granodiorite gneiss, but the exposures are poor, and the supposed dikes probably are inclusions, as the evidence indicates more convincingly that the granodiorite gneiss is younger than the gabbro. The spatial relationship of the granodiorite gneiss to the gabbro and to the Lawler Peak granite could indicate a genetic relationship to either rock, but the closer mineralogic similarity to the Lawler Peak granite might be used as evidence for the conclusion that the gneiss is related genetically to the granite and represents an early stage of the intrusive phase that culminated in the intrusion of the Lawler Peak granite.

The gneiss is essentially concordant with the rocks of the Yavapai series where they are in contact, so the masses near the Hillside mine and several in the Bridle formation can be classified as sills, but where the gneiss cuts the gabbro or the more massive units of the Bridle formation, the outline is more irregular, and these masses can be classified as small stocks. Dikes of granodiorite gneiss also cut the massive rocks.

The granodiorite gneiss generally has a medium-grained texture and gneissoid structure and is composed of quartz, plagioclase, orthoclase, biotite, and accessory sphene. Epidote is secondary. These minerals are readily identified with a hand lens. Locally, south of Sanders Mesa, the granodiorite is massive with only a trace of gneissic structure, and the original plutonic character of the rock is easily determined. In the eastern belt of the Bridle formation some of the small dikes have a porphyritic texture; phenocrysts of plagioclase, quartz, and biotite are embedded in a finely crystalline groundmass. This porphyritic facies is less foliated than the typical granodiorite gneiss.

Thin sections reveal a hypidiomorphic granular texture. The plagioclase ranges from calcic andesine to albite, and epidote granules are common where the plagioclase is sodic. Microcline or orthoclase occur nearly everywhere. Quartz is present as crystalline aggregates, some showing strain shadows. Biotite is greenish and partly altered to chlorite; in some specimens, the biotite has recrystallized to aggregates of small flakes, in others it is primary "book" biotite. Accessory minerals include sphene as granules, apatite as needles, and zircon as prisms. Muscovite occurs in the small bodies along Butte Creek that intrude the Hillside mica schist. Excess of plagioclase over orthoclase (or microcline) indicates an original granodioritic rock. A small amount of myrmekite was recognized in some of the plagioclase in contact with microcline.

The porphyritic facies intrusive in the Bridle formation has oligoclase-andesine phenocrysts in a finely granular groundmass of quartz, feldspar, including orthoclase, and pale-brownish biotite, partly altered to chlorite. Scattered needles of green hornblende may be derived from the Bridle formation. Secondary epidote occurs in small amounts in the plagioclase phenocrysts, and apatite and sphene are minor accessory minerals. This rock was undoubtedly intruded as a granodiorite porphyry.

The mixed granodiorite gneiss and Lawler Peak granite consist in part of gneiss cut by many narrow dikes of granite too small to be shown on plate 3, and in part of a mixed rock. The mixed rock ranges in composition from granodiorite gneiss containing large orthoclase (perthitic) porphyroblasts to a coarse-grained granitic rock in which only the fine scaly biotite indicates the former presence of the gneiss.

LAWLER PEAK GRANITE

A mass of the Lawler Peak granite is well exposed for about 9 square miles in the hilly country in the northeast corner of the area where excellent outcrops on Lawler Peak, suggested this name for the granite. This northern mass of granite is comparatively free of metamorphic rocks, but south of Copper Creek Mesa and Sanders Mesa the Lawler Peak granite occurs in smaller masses associated with the rocks of the Yavapai series, gabbro, and granodiorite gneiss. The granite also crops out west and north of Centipede Mesa in the western part of the area.

The Lawler Peak granite intrudes all formations of the Yavapai series, and gabbro, alaskite porphyry, and granodiorite gneiss. It, in turn, is intruded by the Cheney Gulch granite, by aplite-pegmatite dikes and by the much younger quartz monzonite and its related dikes. The Gila(?) conglomerate and its associated lava flows have accumulated on an erosion surface carved in part from the Lawler Peak granite. The Lawler Peak granite is essentially discordant to the rocks of the Yavapai series, although north of Butte Creek the contact is partly concordant with the Hillside mica schist. At the southeastern margin of the Bridle formation in the southeast corner of the area, the granite was intruded along a fault dividing the Bridle formation from the Hillside mica schist.

Main facies.—The typical Lawler Peak granite is essentially a porphyritic biotite-muscovite granite. Orthoclase phenocrysts as much as 3 inches long are embedded in a medium- to coarse-grained groundmass composed of orthoclase, plagioclase, quartz, biotite, and muscovite. The orthoclase phenocrysts are tabular in habit, the ratio of thickness to width to length averages about 1:2:5. Locally, concentrations of orthoclase crystals are as much as 3 feet long and from 1 to 1½ feet wide. Large orthoclase phenocrysts were observed projecting into two aplite dikes, hinting late growths. However, the phenocrysts generally seem to have been oriented by flowage and must have been formed before complete crystallization of the magma. Oriented phenocrysts define planar structures or swirls in parts of the granite mass (pls. 3 and 5). They must therefore antedate intrusion of the aplite dikes, which presumably occurred after most, if not all, the granite magma had crystallized. Inclusions are rare in the northern exposures of granite, but those with platy form are usually parallel to the planar structure.

In the northern exposures the border facies of granite has large phenocrysts and coarse-grained groundmass at its contact with the older rocks, but in the southern exposures, the border facies is medium grained and the orthoclase phenocrysts are only half an inch long. Contacts with the Butte Falls tuff, the gabbro, and the granodiorite gneiss are poorly defined in places, and considerable soaking of the older rocks by the granitic magma is indicated by orthoclase porphyroblasts. In addition, there are many narrow granitic dikes in the older rocks.

In the southern part of the area, the many "islands" of older rock are presumably roof pendants and xenoliths, and at depth the Lawler Peak granite is probably widespread (pl. 4, *C–C′*, *D–D′*, *E–E′*).

Thin sections show that the orthoclase is perthitic and that the quartz is strained. The plagioclase ranges in composition from albite to albite-oligoclase and is subordinate to the orthoclase. The muscovite and biotite are interstitial to the other minerals, and the biotite is commonly altered to chlorite with the contemporaneous formation of magnetite. Accessory minerals include apatite, sphene, zircon, and fluorite.

Muscovite facies.—In the northern exposures, white muscovite granite forms masses more than a mile in length (pl. 3). Biotite is absent and muscovite is more abundant than in the normal Lawler Peak granite. Thin sections reveal no other difference except that the muscovite has faint pleochroism and fluorite is more abundant. Orientation of the orthoclase phenocrysts is less evident. The transition from the biotite-muscovite facies to the muscovite facies is gradual in some masses and abrupt in others. In broad transition zones bleached biotite is common and can be distinguished from the muscovite only with difficulty. Purple and white fluorite, brown and red garnet, pale-green beryl, and black wolframite crystals are common in narrow quartz veins that cut the muscovite facies. The muscovite granite probably represents a pneumatolytic alteration facies of the biotite-bearing granite or a late-crystallization phase.

Gneissic facies.—The Lawler Peak granite is foliated in the outcrops west and north of Centipede Mesa and in the narrow outcrop between the Bridle formation and Hillside mica schist along Bridle Creek. Inclusions are parallel to the foliation, but their long axes are not always parallel to the linear structure that is marked by alternating bands of light- and dark-colored minerals along the foliation planes. Near Centipede Mesa, this foliated granite is not so coarsely crystalline as the unfoliated granite north of Sanders Mesa, and increase in biotite content near the gabbro, causes a more pronounced foliation. Thin sections reveal considerable granulation of the quartz and show microcline as an important constituent.

The specimens from Mulholland Wash have in place of biotite, shreds of chlorite associated with epidote, coarse sphene, and magnetite. The gneissic facies along Bridle Creek is less porphyritic and has little chlorite, but is richer in biotite, crystals of which are oriented parallel to bands of granulated quartz. The gnessic facies is of considerable importance in dating some of the dynamic metamorphism as occurring later than the intrusion of the Lawler Peak granite.

Altered facies.—North of Sanders Mesa and west of the road to the Hillside mine, a small area of the granite is intensely sericitized, presumably by later hydrothermal alteration. Along Mineral Creek, near the younger quartz monzonite, the granite has been crackled and mineralized through addition of quartz and pyrite. Biotite flakes have recrystallized to leafy aggregates.

CHENEY GULCH GRANITE

The Cheney Gulch granite was named from the good exposures along the west bank of Cheney Gulch, a tributary to Mineral Creek. The largest outcrops of this granite lies in a belt 1 mile long and nearly half a mile wide in the upper part of the Mineral Creek basin. Small outcrops appear to the south between Waters and Crosby Peaks and in the Hillside mica schist east of Bevering Gulch. Three small outcrops are located near Bridle Creek south of Sanders Mesa. To the southeast a band of Cheney Gulch granite crops out between diabase and Hillside mica schist.

The Cheney Gulch granite intrudes the Hillside mica schist and the gabbro, and along their borders near Cheney Gulch, dikes of the Cheney Gulch granite intrude the larger masses of the Lawler Peak granite. South of Sanders Mesa near Bridle Creek, the Cheney Gulch granite is intruded by dikes of aplite-pegmatite. This would limit the time of the intrusion of the Cheney Gulch granite to the interval between the intrusions of the Lawler Peak granite and the aplite-pegmatite. However, some of the small bodies of Cheney Gulch granite spatially associated with the Hillside mica schist southeast of Mineral Creek appear to be intruded by the Lawler Peak granite, as shown by irregular dikes of the latter cutting the Cheney Gulch granite, and by the growth of orthoclase porphyroblasts in the Cheney Gulch granite. It is assumed therefore, that magma intruded during two different stages of the same general intrusive period and formed granites of similar character. The rock mapped as Cheney Gulch granite in the southeast corner of the area resembles typical Cheney Gulch granite rather closely except for a slightly finer grain size and a smaller biotite content. This southeastern granite is intruded by the Lawler Peak granite.

The Cheney Gulch granite is fine to medium grained with a hypidiomorphic granular texture. Thin sections reveal sodic plagioclase ranging in composition from albite to albite-oligoclase; the cores of some crystals are more calcic and are clouded by epidote and sericite. Subhedral to euhedral sodic plagioclase is slightly subordinate to the anhedral to subhedral orthoclase and microcline. Quartz is abundant and shows some strain shadows. Biotite occurs as ragged crystals, some altered to chlorite. Epidote granules are commonly associated with the biotite. Sphene, magnetite, and apatite are conspicuous accessory minerals, whereas zircon is a minor accessory mineral.

The granite in the southeast corner of the area is more aplitic in texture and albite is appreciably subordinate to orthoclase. Biotite is unaltered and occurs in a smaller quantity. Quartz is an important constituent. Garnet, zircon, apatite, and tourmaline are minor accessory minerals.

APLITE-PEGMATITE

The aplite-pegmatite occurs as dikes, sills, pods, and large masses concentrated largely in the metamorphic rocks near the border of the Lawler Peak granite and in the granite. Most of the dikes are in the area south of Sanders Mesa; some pass into larger masses. In the gabbro mass southeast of Sanders Mesa, aplite-pegmatite dikes are abundant but only the dikes that were conspicuous on the aerial photographs are shown on plate 3. Their precise location was not checked in all details in the field. The dikes range in width from several inches to more than 100 feet, but the only ones plotted are those 10 feet or more in width. Most of these dikes range from 20 to 30 feet in width, and the dominant trends are north, N. 30° E., west, and N. 60° W. South of Centipede Mesa the dikes in the gabbro are parallel to the structure in the gabbro. The largest mass of aplite-pegmatite south of Nelson Mesa is exposed for more than a mile in a northerly direction and more than half a mile to the east. The eastern margin is beyond the limits of the map. Smaller masses crop out to the southwest of this large mass and in the Lawler Peak granite north of Sanders Mesa. Near the Hillside mine, the aplite-pegmatite bodies are parallel to the foliation of the mica schist and are sill-like in form.

The aplite-pegmatite dikes and masses intrude the Bridle formation, Hillside mica schist, gabbro, and Lawler Peak and Cheney Gulch granites. The composition and spatial relationship of the aplite-pegmatite to the Lawler Peak granite indicate a genetic relationship to the granite, the aplite-pegmatite bodies in large part represent the closing phase of intrusive activity related to the Lawler Peak granite. In Urie Basin, north of Boulder Creek, the gradation of a large aplite-pegmatite dike into the muscovite facies of the Lawler Peak granite, suggests a close relationship. On the other hand, aplite dikes are visible in the walls of a ravine tributary to Maroney Gulch and in the area north of the Cowboy Peaks. These aplite dikes apparently were intruded by Lawler Peak granite, which suggests that some aplite dikes may be older than this granite, a relationship similar to that of some bodies of the Cheney Gulch granite.

Most of the aplite-pegmatite consists of a mixture of white sugary aplite and coarse-grained pegmatite. The ratio is not uniform, but on the average about half of the rock is pegmatitic and occurs as bands and pods. The large masses of aplite-pegmatite are visible from a distance, because of their white outcrops and lack of conspicuous jointing. Some of the narrow dikes are aplitic and without associated pegmatite. The dikes near the Comstock-Dexter mine contain a little biotite; elsewhere, biotite is absent. Muscovite occurs in some of the aplite dikes in the Lawler Peak granite. In some specimens of aplite, where the dominant feldspar is albite or albite-oligoclase, the rock texture is hypidiomorphic and these rocks might be termed alaskites. In other specimens in which microcline is greatly in excess of the albite, the texture is aplitic or allotriomorphic granular. Quartz showing local strain shadows is always an important constituent. Apatite and sphene are common accessory minerals in the aplitic facies.

The pegmatitic facies consists of quartz and microcline, in places in graphic intergrowth; some microcline crystals are 6 to 8 inches long, and the quartz crystals are commonly 4 inches long. Albite occurs as small crystals in the microcline or as a perthitic intergrowth. Greenish-white muscovite is a common accessory mineral, and the crystals measure about 1 inch in diameter. Black tourmaline is also common; it is sporadic; locally prisms are as much as 4 inches long, but most of the crystals are less than an inch long. In places the tourmaline crystals grew perpendicular to the margin of the pegmatite. Near the southwest corner of Nelson Mesa, ellipsoids of quartz and tourmaline were found in the aplitic facies, and these ranged from ½ to 1 inch in length. Garnet as single crystals and as massive aggregates was found in several pegmatite masses. Small greenish-blue to greenish-white beryl crystals that average one-half inch in diameter occur in many of the pegmatite masses, but a few crystals as large as 1 inch were found. The beryl occurs in bunches limited to an area several square feet in diameter. Granular lepidolite was found in the southeastern part of the area, ramifying throughout the pegmatite in 3-foot stringers, 2 inches to 1 foot wide. Flaky crystals of lepidolite occur in small clots in the pegmatite north of the White Spring fault. Allanite as small black irregular crystals was found in pegmatite float north of Bull Spring. Pinkish-brown amblygonite crystals as much as 4 inches long and white topaz crystals 6 to 8 inches long were found in pegmatite southeast of Lawler Peak. Julius Commod (oral communication) reported that triplite occurs near Lawler Peak, but none could be found during our study. In the area east of Lawler Peak, straw-colored fibrous bismutite, presumably a secondary mineral replacing bismuthinite, was found by Julius Commod. The bismutite occurred in small pockets in the quartz-rich facies of the pegmatite or in some of the quartz veins cutting the pegmatite. White and purple fluorite is commonly associated with the bismutite.

To the east and southeast of the mapped area in similar pegmatite masses, amblygonite, triplite, and lepidolite have been found by Julius Commod who also discovered the triplite and bermanite locality near the 7U7 Ranch, 7 miles southeast of Bagdad (Hurlbut and Gonyer, 1936).

AGE OF THE INTRUSIVE ROCKS

Normal stratigraphic evidence is not available to prove that the oldest intrusive rocks, culminating in aplite-pegmatite, are pre-Cambrian. The Yavapai series in the Bagdad area has similar lithologic features and metamorphic structures to the known pre-Cambrian rocks in the Prescott-Jerome area. The Bagdad intrusive rocks intrude the Yavapai series, and except for the Cheney Gulch granite and aplite-pegmatite, these intrusive rocks are locally metamorphosed to schist and gneiss. The general parallelism of the foliation in the intrusive rocks to the foliation in the adjacent Yavapai series suggests contemporaneous deformation and is probably the most convincing argument that the intrusive rocks are related in time to the deformation of the Yavapai series.

In southern Arizona (Butler and Wilson, 1938a), sedimentary rocks of Paleozoic and Mesozoic age are commonly schistose, owing to late Mesozoic or early Tertiary orogeny and intrusion of granitoid rocks. In the absence of stratigraphic evidence, some doubt can be raised as to the pre-Cambrian age of the metamorphic and older intrusive rocks in the Bagdad area. Fortunately, radioactive age determinations of minerals from the Bagdad area have been made by L. T. Aldrich and G. L. Davis (oral communication, 1955) of the Carnegie Institution's Department of Terrestrial Magnetism and Geophysical Laboratory. They report that based on potassium-argon and rubidium-strontium measurements on muscovite from the Lawler Peak granite and lepidolite from an associated pegmatite dike, the best figure for the age is 1,600 million years, clearly proving the pre-Cambrian age of the Lawler Peak granite and older Yavapai series.

In the vicinity of Mazatzal Peak, Wilson (1939) has recognized formations younger than the Yavapai series, the chief unit being the Mazatzal quartzite. A period of orogeny, Wilson's Mazatzal Revolution, marked by folding and faulting of the Yavapai series and the Mazatzal quartzite, preceded the intrusion of granite. This granite is older than the Apache group of the Upper pre-Cambrian. Anderson (1951, p. 1346) concluded that until more precise correlations of the older pre-Cambrian rocks in Arizona can be made, the simplest explanation is that only one period of orogeny, which corresponds to Wilson's Mazatzal Revolution, has occurred in Arizona during the early pre-Cambrian. Until contradictory evidence is available, the tentative conclusion is made that in the Bagdad area, a series of intrusive rocks, the latest being aplite-pegmatite, were intruded during and after the Mazatzal Revolution and are older pre-Cambrian.

ROCKS OF LATE CRETACEOUS(?) OR EARLY TERTIARY(?) AGE

GRAYBACK MOUNTAIN RHYOLITE TUFF

The Grayback Mountain rhyolite tuff is exposed only on Grayback Mountain, which is the highest elevation in the region. Less than one-half square mile of the tuff was mapped in this study, but it underlies much of the summit of Grayback Mountain beyond the limits of the area shown on plate 3.

The Grayback Mountain rhyolite tuff rests on an irregular erosion surface of moderate relief that in the vicinity of Grayback Mountain is carved principally on the alaskite porphyry. Three breccia pipes, apparently older than the tuff, underlie it, but dikes of rhyolite and diorite porphyry invade the tuff.

The tuff is rather massive, but as viewed from a distance a very thick bedding is suggested. Owing to the irregular surface of the base and to the erosion of the top, the thickness of the tuff is not uniform; about 500 feet of tuff is exposed in the thicker sections. Some samples resemble flow rock, but a fragmental texture is revealed on many weathered surfaces. The fragments are largely lithic rhyolite and alaskite porphyry, mostly of lapilli size. Quartz and feldspar crystals are embedded in a brownish base that is resolved under the microscope as a pyroclastic matrix consisting of crystallized shards, the outlines of which suggest an original glassy character. Some spherulitic aggregates have formed in some of these shards. The fragments of rhyolite include massive and flow-banded varieties and contain resorbed quartz and rectangular albite phenocrysts in a microcrystalline or cryptocrystalline groundmass. Crystal fragments include quartz, albite, and orthoclase, and all three minerals could have been derived from the underlying alaskite porphyry as well as from the rhyolite magma. The tuff can be classified as lithic-crystal-vitric.

The pyroclastic texture of the rock proves that it is a tuff, and the massive character eliminates water and wind as probable transporting agents. The superficial resemblance to flow rocks and the presence of crystallized shards, both characteristic features of welded tuffs, suggest that the tuff was emplaced by pelean eruptions, which produced clouds of gas-rich ejecta that avalanched down the sides of a volcano and accumulated as tuff. During and immediately after accumulation the gas-rich ejecta collapsed, crystallized, and became welded (Gilbert, 1938).

A long period of erosion can be postulated after the deformation of the Yavapai series and subsequent intrusion of the oldest igneous rocks, and before the deposition of the nonmetamorphosed Grayback Mountain rhyolite tuff (pl. 4, *D–D′*), because the tuff is discordant structurally to the metamorphosed Yavapai series and rests on an erosion surface carved on the alaskite porphyry. The only exposure of this surface is found on Grayback Mountain, but this surface must have been extensive in the Bagdad area before it was covered by the tuff. No evidence is available, however, to date the time of accumulation of the tuff. By analogy to similar rocks in Arizona, the age is assumed to be probably Late Cretaceous or early Tertiary (Butler and Wilson, 1938a, p. 15), as volcanic rocks of Paleozoic and early Mesozoic age of this character are unknown in Arizona. The Grayback Mountain rhyolite tuff may be related to the volcanic rocks in the Oatman district, 75 miles to the west-northwest of Bagdad, which were assigned to the Tertiary by Ransome (1923, p. 11–30).

INTRUSIVE YOUNGER RHYOLITE

Intrusions of younger rhyolite are limited to the southwestern part of the area where the Bridle formation is exposed, except for one dike along Boulder Creek above its junction with Copper Creek, one dike in the southeast corner of the area near Bridle Creek, and one plug along Boulder Creek north of Butte Falls.

The rhyolite occurs as dikes, sills, small pods, and plugs intrusive largely into the Bridle formation. Most of the tabular bodies of rhyolite are parallel to the structure of the volcanic rocks, indicating sills, but some cut across the structure. Dikes of rhyolite cut the alaskite porphyry, and also some of the breccia pipes and the Grayback Mountain rhyolite tuff. The rhyolite plug at Lucy Peak has a dike offshoot that extends south for 2,000 feet, parallel to the contact of the King Peak rhyolite and Butte Falls tuff. Another dike is intruded along the Mountain Spring fault. The rhyolite is intruded by the quartz monzonite, diorite porphyry, and quartz-monzonite porphyry dikes.

The rhyolite is conspicuously white, therefore the outcrops are sharply defined where the intruded rock is the dark-colored Bridle formation or the brown alaskite porphyry. Quartz phenocrysts are conspicuous, and plagioclase phenocrysts, determined microscopically to be albite, are common. The groundmass ranges in texture from almost glassy, in the chilled selvages, to microcrystalline. In the centers of some of the thicker rhyolite sills and dikes, the color is slightly more gray and biotite is an accessory mineral. Flow banding occurs along some of the margins of the dikes and plugs. Some of the dikes and sills in the southwestern area and the plug along Boulder Creek are brecciated, and the fragments are tightly packed.

QUARTZ MONZONITE

Quartz monzonite is exposed in a series of stocks and plugs that trend N. 70° E. and extend from Mammoth Wash on the west to Nelson Mesa on the east. The largest stock underlies the town of Bagdad and contains the copper ore body; it is exposed for more than a mile in an irregular outline to the northwest and northeast. A second stock, north of Nelson Mesa, crops out for a mile to the northeast, but is less than half a mile wide. Small outcrops of quartz monzonite south of the mesa are presumably the southern margin of this stock. A third stock, between Mammoth Wash and Alum Creek, is 4,000 feet long and 500 to 1,000 feet wide; a narrow offshoot extends 1,000 feet to the southeast. The other outcrops, except one south of Mammoth Wash, 2,000 feet long, are small—1,000 feet or less in length.

Dike offshoots of the quartz monzonite are so rare that the intrusive relationship to the neighboring rocks is difficult to determine, but clear-cut intrusive contacts were obtained with reference to the rocks of the Yavapai series, the alaskite porphyry, and the Lawler Peak granite. Roof pendants of the granite are present in the stock at Bagdad. The pattern of the outcrops of many of the smaller masses also indicates intrusive relationship. The quartz monzonite and dikes of diorite porphyry that appear to be genetically related to it are younger than the latest intrusions of rhyolite and also younger than the Grayback Mountain rhyolite tuff; for rhyolite dikes intrude the tuff, and in turn the rhyolite dikes are cut by the quartz monzonite. Many dikes of quartz monzonite porphyry intrude the quartz monzonite, but only one of the dikes of diorite porphyry is present in the quartz monzonite. The Gila(?) conglomerate was deposited on an irregular erosion surface, carved in part on the quartz monzonite.

The quartz monzonite weathers readily to a friable material, and exposures are poor, except for those of unweathered rock in canyon floors or in those places where the rock has been hydrothermally altered and enriched in quartz. Specimens of unaltered rock range in texture from porphyritic (fig. 8) to seriate. The plagioclase ranges in composition from calcic oligoclase to andesine; locally, albitic borders are present. The plagioclase occurs as euhedral to subhedral crystals of variable size. Orthoclase is present as equant grains, subhedral to anhedral, and generally smaller than and interstitial to the plagioclase. In most thin sections examined, plagioclase is in excess of orthoclase. Quartz occurs as small interstitial crystals, rarely in graphic intergrowth with orthoclase. Subhedral to anhedral biotite, partly altered to chlorite, is a common accessory mineral. Hornblende prisms, pleochroic in shades of green, are variable in distribution. In some places hornblende is in excess of biotite, and in others, biotite is in excess. Minor accessory minerals include sphene, magnetite, apatite, and zircon.

Aplitic dikes, 1 to 3 feet wide, cut the quartz monzonite, and these are composed of perthitic orthoclase locally showing Carlsbad twins. Orthoclase and subordinate sodic oligoclase are assocated with abundant irregular grains of quartz. In the stock north of Nelson Mesa, black tourmaline in irregular blotches occurs in the aplite dikes.

Much of the unaltered rock closely approaches a granodiorite in composition (see section on alteration, p. 52–54), but in the hydrothermally altered facies, orthoclase and plagioclase are nearly equal in amount, and for some time the term "quartz monzonite" has been used for these rocks in the Bagdad area. Because the differences between quartz monzonite and granodiorite are not great, it seems desirable to retain the term "quartz monzonite."

The stock at Bagdad has been mineralized with sulfides, chiefly pyrite and chalcopyrite, and the hydrothermally altered parts of the quartz monzonite are more equigranular in texture than the unaltered rock, owing to the introduction of secondary orthoclase that approaches the plagioclase in grain size. The andesine of the original rock is altered to albite, and the book biotite has recrystallized to leafy aggregates. Locally the quartz monzonite has been silicified and considerable coarse sericite (or muscovite) has formed. Many of the outcrops around Bagdad have been further altered by sulfuric acid solutions generated by the oxidation of the sulfides.

The stock north of Nelson Mesa shows neither fracturing nor mineralization, but the smaller stocks and plugs between Mammoth Wash and Bagdad are locally fractured and mineralized and contain small amounts of sulfides. The southwestern outcrops are almost barren of sulfides.

No direct evidence is available to date the intrusion of the quartz monzonite stocks in the geologic time scale. However, the evidence indicates this sequence of events: erosion of the rocks of the pre-Cambrian complex, accumulation of pyroclastic rocks (Grayback Mountain tuff), intrusion of dikes of younger rhyolite, and intrusion of the quartz monzonite. Butler and Wilson (1938b, p. 99) stated that the age of the quartz monzonite was not known, but that it might be Laramide. This suggestion may gain added support from the knowledge of the relationship of the Grayback Mountain rhyolite tuff to the quartz monzonite. In other regions in Arizona a period of igneous activity beginning in Late Cretaceous time produced lava flows and pyroclastic accumulations that were accompanied or followed by intrusions of batholiths, stocks, and dikes of rock monzonitic to granitic in composition (Butler and Wilson, 1938a, p. 11). Like these rocks, the quartz monzonite of the Bagdad area is considered to be Late Cretaceous or early Tertiary.

DIORITE PORPHYRY

Dikes and plugs of diorite porphyry are limited largely to the southwest corner of the Bagdad area, especially near the southeastern margin of the zone of quartz monzonite stocks and plugs. Some quartz diorite porphyry intrusives have been included with the diorite porphyry. The dikes, with few exceptions, have a northeast trend. A few dikes (or sills) are present in the Butte Falls tuff and Hillside mica schist along Boulder Creek south of the Hillside mine. Several dikes south of Sanders Mesa that differ from the typical diorite porphyry nevertheless have been mapped as such. One dike of diorite porphyry occurs in the Lawler Peak granite north of Sanders Mesa. A composite dike (or sill) of diorite porphyry and rhyolite more than a mile long and as much as 400 feet wide crops out north of Grayback Mountain; its trend ranges from east to northeast.

The diorite porphyry is intrusive into almost all the rocks older than the quartz monzonite, but only one of the dikes actually penetrates the quartz monzonite. The general similarity in texture and mineral composition of the quartz diorite porphyry to the border facies of some of the quartz monzonite and the spatial relationship of the two rocks suggests that the quartz diorite magma or a differentiate of it was injected shortly after the stock and plug intrusions of quartz monzonite. The dikes of diorite porphyry may be slightly younger than those of the quartz diorite porphyry. The dikes of quartz monzonite porphyry have a northwest trend and intrude the dikes of diorite porphyry.

Many of the tabular bodies of the diorite porphyry intrude massive rocks, but locally in the Bridle formation they are concordant with the structure and should be termed "sills." However, some of these extend from the foliated volcanic rocks into massive rocks, where technically they are "dikes," and others cut the structure of the Bridle formation, so throughout this discussion, the term "dike" will be used.

The diorite porphyry weathers to buff-colored outcrops, most of which are slightly more resistant to erosion than those of the surrounding rocks. The average width of the dikes ranges from 20 to 30 feet. In a few places, as observed southeast of King Peak, the dikes extend outward from plugs. Some of the isolated outcrops are small and lenticular and suggest "plug" as an appropriate term to describe the intrusions. The typical diorite porphyry is conspicuously porphyritic and contains plagioclase phenocrysts and chlorite pseudomorphs after biotite phenocrysts. Hornblende phenocrysts are common. The plagioclase phenocrysts range in composition from albite to andesine, and the more sodic varieties contain sericite. Chlorite and epidote have replaced all biotite phenocrysts, but some of the hornblende phenocrysts have been replaced by aggregates of leafy greenish-brown biotite. Quartz phenocrysts were noted in some of the dikes, and quartz also was observed in the groundmass of some specimens from the dikes in which quartz phenocrysts were absent. A complete transition from quartz-bearing to quartz-free diorite porphyry dike rocks was found but the quartz-bearing facies is subordinate, and it has not been differentiated on plate 3. The microcrystalline groundmass is composed of interlocking crystals of alkalic feldspar with or without quartz. The alkalic character of the groundmass feldspar suggests hydrothermal alteration. Specimens from the plugs have a slightly coarser groundmass, but otherwise they are similar in mineral composition and texture to the dike rocks. All facies contain accessory sphene, magnetite, apatite, and zircon.

In the composite dike of diorite porphyry and rhyolite, both rocks locally have chilled edges at their contact indicating that the younger intrusion of diorite porphyry in places followed the margin of the older dike of rhyolite. The best evidence for the younger age of the diorite porphyry is the presence of fractured rhyolite surrounded and intruded by unfractured diorite porphyry, which indicates that some movement occurred along the dike zone in the interval between intrusions. At one locality in the composite dike, a breccia dike 1½ feet wide separates the diorite porphyry from rhyolite, and each igneous rock has chilled edges against the breccia.

The dike cutting the Lawler Peak granite north of Sanders Mesa is less resistant to erosion than the granite and can be traced only with difficulty. Quartz phenocrysts indicate that this dike is an intrusion of quartz diorite porphyry.

The few dikes south of Sanders Mesa are gray rocks containing conspicuous black hornblende phenocrysts in a finely crystalline groundmass of oligoclase separated by chlorite, epidote, and rarely by quartz. These hornblende diorite porphyry dikes cut the aplite-pegmatite, proving that they are younger than the Lawler Peak granite and related rocks, but the only evidence for their correlation with the quartz monzonite and related rocks is their general similarity in composition to the other diorite porphyry dikes and their similar northeast trend. It is possible that they are unusual lamprophyric dikes related to the Lawler Peak granite.

Short and narrow dikes, 1–2 feet wide, dark gray, and containing plagioclase and biotite phenocrysts in a microcrystalline groundmass, occur in the quartz monzonite near Bagdad. These rocks weather easily, and coherent samples suitable for thin sections are impossible to obtain. These dikes have been called trachyte in some of the private reports for Bagdad Copper Corp. and its predecessors, but the composition and texture are more indicative of diorite porphyry. The outcrops are too small to be shown on plate 3.

QUARTZ MONZONITE PORPHYRY

Quartz monzonite porphyry crops out as dikes in a belt more than a mile wide extending from Waters Peak, in the south-central part of the area, north-northwestward to the Hillside mine, along Boulder Creek. One dike follows the Mountain Spring fault for more than 1,000 feet north of Mountain Spring. Plugs of quartz monzonite porphyry are concentrated in the area between Alum and Niagara Creeks, and the largest plug is less than 1,000 feet in diameter.

The quartz monzonite porphyry dikes intrude the quartz monzonite and diorite porphyry and all older rocks. The plugs chiefly intrude breccia pipes or rocks adjacent to the pipes, but a few occur in some of the smaller quartz monzonite stocks.

Most of the dikes range from 10 to 30 feet in width, but a few are as much as 150 feet wide. The main trend of the dikes is from north-northwest to north, though a few isolated dikes trend northeastward. The dikes are discontinuous and in places are arranged en echelon. South of Butte Creek, one "dike" has columnar joints spaced about 1 foot apart. This "dike" is parallel to the foliation of the schists and is properly a sill.

The quartz monzonite porphyry is appreciably hydrothermally altered, and the original minerals except quartz are largely changed. Quartz phenocrysts are conspicuous in most specimens, and altered feldspar can be recognized, but the plagioclase and orthoclase are difficult to distinguish, except in a few specimens. Thin sections containing recognizable feldspars reveal albite, sericitized in part, and orthoclase in different ratios. Each may be in excess of the other in different thin sections. Biotite was an original phenocrystic mineral, and a few unaltered flakes were found, but usually it is indicated by hexagonal-shaped cavities containing shreds of yellow or white muscovite adhering to the walls. The groundmass is light colored and microcrystalline in the dikes, but in the plugs, it is finely crystalline and composed of quartz and alkalic feldspar. Calcite and epidote aggregates are common in the groundmass. Pyrite occurs as disseminated crystals and where oxidized, forms a brown to buff coating of iron oxide on the outcrops. Owing to the altered nature of the rock, no positive estimate can be made of the ratio of orthoclase to plagioclase, or of the anorthite content of the original plagioclase. The tentative classification as quartz monzonite porphyry is based solely on the presence of quartz, orthoclase, and plagioclase as phenocrysts.

The differentiation of the hydrothermally altered quartz monzonite porphyry from the similarly altered quartz monzonite is a difficult problem in the field, and some bodies of the porphyry may not have been differentiated in the mapping of the stock at Bagdad.

ROCKS OF LATE TERTIARY(?) AND PLEISTOCENE(?) AGE

GILA(?) CONGLOMERATE

A conglomerate provisionally correlated with the Gila conglomerate is exposed along the mesa walls and in the walls of the canyons cutting into the mesas. It crops out as an almost continuous band from east of Nelson Mesa to the canyon walls of Boulder Creek between Bozarth and Centipede Mesas, and isolated patches crop out east and west of Boulder Creek, near the Hillside mine. Almost continuous exposures are located north of Boulder Creek and Wilder Creek canyons in the northern part of the area and small outcrops occur under a small mesa north of Nelson Mesa. One small patch of conglomerate crops out south of Maroney Gulch, a second crops out south of the east end of Centipede Mesa, and a third and much larger outcrop is located west of Mulholland Basin.

The Gila(?) conglomerate is essentially a valley-fill deposit consisting of nonvolcanic sediment and rhyolitic tuff. The conglomerate and the intercalated basaltic lava flows and basaltic tuff of the Wilder formation and flows of the Sanders basalt accumulated on an erosion surface that was carved on the pre-Cambrian and younger rocks and had a relief as great or greater than the present erosion surface. Deposits of this character have a greater thickness in the troughs of former canyons. The Gila(?) conglomerate is more than 700 feet thick where exposed on the southern wall of the Boulder Creek canyon, and if the intercalated lava flows are included, 1,000 feet or more of sediment and lava accumulated on the old erosion surface. However, the bottoms of several former canyons filled by the Gila(?) conglomerate have not been exposed by present erosion. On Nelson Mesa 50 feet of Gila(?) conglomerate is exposed above the Sanders basalt, the youngest of the lava flows; therefore no maximum thickness can be assigned. Outcrops range from a few feet to 700 feet in thickness.

The intercalated basaltic flows and basaltic tuffs are more common in the western and northern outcrops near the margin of Bozarth Mesa and in Wilder Creek canyon. The outcrops beneath Black, Copper Creek, Sanders, and Nelson Mesas have a greater amount of sedimentary nonvolcanic material. These mesas mark the course of a valley, now filled by Gila(?) conglomerate, determined in large part by the friable character of the outcrops of the readily weathered quartz monzonite.

The Gila(?) conglomerate largely is composed of poorly indurated boulder to pebble gravel containing interbeds of compacted sandstone and siltstone. Much of the basal part of the conglomerate is poorly bedded and poorly sorted and contains angular to subrounded cobbles and boulders. The upper part is better sorted and consists of pebble conglomerate, sandstone, and coarse siltstone in beds of about 1 foot thick. The fragments are of local source, and near the outcrops of Lawler Peak granite, the conglomerate is composed mostly of fragments of this granite; in places, boulders as much as 5 feet in diameter are common. In Mesa Pass and near Nelson Mesa aplite-pegmatite fragments are conspicuous, and gabbro fragments are common in the basal part of the Gila(?) conglomerate. West of Mulholland Basin, the basal part is rich in gabbro debris, whereas the upper part contains abundant fragments of alaskite porphyry and Grayback Mountain rhyolite tuff. Some volcanic debris occurs in the Gila(?) conglomerate, particularly in the western and northern exposures, but even between Copper Creek and Sanders Mesa scattered rhyolite pumice fragments occur.

At the western tip of Copper Creek Mesa, a 10- to 20-foot section of limestone, overlying the Sanders basalt is exposed. The limestone is white to gray, rather chalky except for the well-indurated uppermost foot or so. Some clastic material, largely sand grains, is embedded in the limestone, which has been protected from erosion by an eastward tilt of the underlying lava that is related to the Hillside fault. In the small canyon that cuts eastward into Bozarth Mesa north of Boulder Creek, 10 or more thin beds of limestone, each averaging about 1 foot in thickness, are interbedded with sandstone. Along Copper Creek, calcareous sandstone concretions make up 2 beds, each 3 feet thick.

On Nelson Mesa the sedimentary rock, younger than the Sanders basalt, contains 15 feet of sandy rhyolite tuff mixed with aplite and granite debris the size of coarse sand. This tuff is overlain by 35 feet of conglomerate made up of pebbles and cobbles of granite and Sanders basalt. On Bozarth Mesa quartz and schist pebbles cemented in several patches of caliche indicate the former presence of Gila(?) conglomerate above the Sanders basalt. Loose pebbles of nonvolcanic rock are common in some of the other mesas and indicate a former cover of Gila(?) conglomerate.

Rhyolite tuff beds.—Rhyolite tuff beds are interbedded in the Gila(?) conglomerate at several places. Along Wilder Creek and in the headwaters of Contreras Wash, tuff beds as much as 3 feet thick occur in the lower part of the Gila(?) conglomerate. At the western margin of the area in the short canyon cutting into Bozarth Mesa, several beds of rhyolite tuff are exposed, too thin, however, to be shown on plate 3. A thicker bed of rhyolite tuff separates the Gila(?) conglomerate from the Sanders basalt in the crescent-shaped belt of mesas (pl. 1*A*) that extend from Nelson Mesa on the east to Centipede Mesa on the west. This bed of tuff is generally 15 to 20 feet thick but ranges in thickness from 1 to 50 feet, the greater thickness is along the west edge of Centipede Mesa.

The tuff is poorly stratified but thinly bedded. Most of the volcanic material is white pumice lapilli and ash. At several places beneath the overlying Sanders basalt the presence of a red facies suggests baking by the overlying lava. At some places, particularly near Copper Creek Mesa, the tuff is largely altered to clay. Elsewhere, the tuff locally is altered to a grayish-white cavernous opal rock, and locally along the eastern margin of Bozarth Mesa the tuff is completely replaced by black opal and resembles obsidian. In places the rhyolite tuff contains nonvolcanic detritus.

Age and correlation.—Sedimentary rocks of Cenozoic age ranging in composition from coarse gravel to clay and containing intercalations of volcanic rocks are widespread throughout Arizona. It has been common practice to correlate these rocks in their various occurrences, with the Gila conglomerate (Butler and Wilson, 1938a, p. 14), a rock that was first described by Gilbert (1875, p. 540–541) from exposures along the Gila River in the southeastern part of Arizona. Vertebrate fossils from the San Pedro Valley (Gidley, 1922; 1926) and from the Gila and San Simon Valleys (Knechtel, 1936, p. 87) prove a late Pliocene age for the Gila conglomerate, although Knechtel (1936, p. 86) states that some of the deposits along the upper Gila River may be Pleistocene.

No precise correlation is possible between the conglomerate at Bagdad and the Gila conglomerate in the southeastern part of Arizona. Our tentative correlation with the Gila conglomerate is based on the general similarity in lithology and relationship to older rocks, and the name Gila(?) is used because many geologists are familiar with the character of the Gila conglomerate. Some geologists would doubtless prefer to use a local term, but the writers believe that a tentative correlation with the Gila conglomerate, is preferable to the introduction of a new stratigraphic term for the Bagdad occurrence.

A recent discovery of vertebrate fossils has been made south of Prescott along Milk Creek, in sedimentary rocks similar to the Gila(?) conglomerate at Bagdad. The fauna proves an early Pliocene age for the gravel, sand, clay, and rhyolite tuff that contains intercalated dacitic and basaltic flows (Lance, J. F., oral communication, 1952). It seems best therefore to suggest that the age of the Gila(?) conglomerate at Bagdad may be late Tertiary(?) and Pleistocene(?).

WILDER FORMATION

The Wilder formation is well exposed along the walls of Wilder Canyon, hence the use of this name for this series of rocks. The formation also crops out to the east of Wilder Creek, along the north wall of Boulder Canyon; to the south, along the west wall of Boulder Canyon; and along the eastern margin of Bozarth Mesa. Some small outcrops occur southeast of the Hillside mine. Excellent exposures are revealed in the canyon walls of Boulder Creek west of its junction with Copper Creek, and a small outlier occurs west of Mulholland Basin.

The Wilder formation in Wilder and upper Boulder Canyons is intercalated throughout the Gila(?) conglomerate with units at the base, middle, and top of the section. On the west bank of Wilder Canyon, Sanders basalt is intercalated with and overlies the Wilder formation, but elsewhere the Sanders basalt is separated from the underlying rocks by an erosion surface of low relief or by one of the rhyolite tuff beds of the Gila(?) conglomerate. The aggregate thickness of the Wilder formation generally ranges from 200 to 300 feet, but west of Contreras Wash, 400 feet is exposed.

The Wilder formation comprises lava flows, intrusive plugs, pyroclastic cones, and horizontally bedded tuffaceous rocks.

Lava flows.—Typical lava of the Wilder is bluish gray and contains coarse phenocrysts of black augite and small phenocrysts of olivine embedded in a fine-grained to microcrystalline groundmass. The augite phenocrysts are as much as one-quarter of an inch long. The olivine is generally altered to reddish iddingsite. The flows are locally vesicular and have frothy scoriaceous tops. Platy jointing is rather common.

The augite is almost colorless in thin section, and locally it is poikilitic (ophitic) from inclusions of labradorite. In part, the groundmass has an intergranular texture, in which euhedral crystals of labradorite are separated by granules of colorless augite and crystals of magnetite. A few microphenocrysts of calcic labradorite occur locally. In some specimens the groundmass texture is pilotaxitic in which there is a crude parallel arrangement of the plagioclase microlites. The mineral components indicate that the lava flows are basaltic in composition, but a chemical analysis might indicate andesitic composition. In this report the lava in the Wilder formation will be termed "basalt."

The oldest flows, exposed in a westward-flowing tributary of Wilder Creek, are badly altered, but they resemble the Sanders basalt in having a more coarsely crystalline texture and coarser vesicles.

Intrusive plugs.—A large plug or neck of massive lava of the Wilder formation occurs in the Gila(?) conglomerate on the north side of Boulder Creek below Bozarth Mesa (pl. 1*B*). The texture and mineral composition are similar to those of the flows, but vesicles are rare. Dikes of similar rock were noted in the rhyolite plug to the northeast along Boulder Creek north of Butte Falls, and two dikes of more altered lava cut the Hillside mica schist southwest of the Hillside mine. A small circular plug of lava of the Wilder formation intrudes the Lawler Peak granite about a mile northwest of Lawler Peak. Here, fragments of granite and quartz grains have been incorporated in the lava and pale-green diopside crystals form rims around the quartz grains. The feldspar is albitic in composition and contains many reddish needles of rutile(?), and augite granules are more irregularly distributed than in the typical basalt of the Wilder formation.

Pyroclastic cones.—Deposits of reddish pyroclastic basaltic material are exposed along the east and south walls of Bozarth Mesa, in the bottom of Wilder Creek, and on the hill east of the Hillside mine. Many of these deposits are massive and the bombs, lapilli, and ash are partly welded together, which suggests that the fragments were hot enough at the time of accumulation to adhere to each other. Other exposures show steeply inclined beds that dip from 35° to 40°. Most bombs are spindle-shaped and range from 1 to 1½ feet in length. Along the east wall of Bozarth Mesa, lava flows that are parallel to the steep bedding of the pyroclastic rocks indicate the structure of a composite cone; some dikes of basalt in the Wilder formation cut across the bedding of the cone. Elsewhere, the pyroclastic rocks represent simple cinder-cone accumulations. The vertical distribution of the cone material suggests that explosive eruptions took place throughout the period of accumulation of the Wilder formation. Some of the cones appear at the base of the section, as on Wilder Creek. One cone remnant east of the Hillside mine rests on basalt flows of the Wilder and is overlain by arkosic sandstone and rhyolite tuff of the Gila(?) conglomerate. This suggests that here the volcanic cone formed late in the history of the Wilder formation and the Gila(?) conglomerate.

Horizontally bedded basaltic tuff.—The horizontally bedded tuffaceous rocks shown on plate 3 as included in the Wilder formation are actually a part of the Gila(?) conglomerate, but they are included in the Wilder formation in order to show their genetic relationship to it. The beds are composed of fragments derived from the Wilder formation, particularly of material from the pyroclastic cones. The fragments include basaltic lapilli and ash, pumiceous to scoriaceous in structure, and bluish gray to red. Some lava fragments are also present. Bedding is well developed and parallel to the beds in the nearby nonvolcanic Gila(?) conglomerate. In the northern exposures of the Gila(?) conglomerate, these basaltic fragments are important constituents of the beds and are mixed with the normal nonvolcanic debris, but only where the beds are composed largely of volcanic debris, have they been separated into bedded tuffaceous rocks of the Wilder formation. The horizontally bedded tuff is located near the pyroclastic cones and the grain size of the volcanic fragments decreases away from the cones. The thickest section of the water-deposited tuff occurs west of Contreras Wash., where 400 feet of horizontally bedded tuff has filled an old valley. Some calcite is present as cementing material.

SANDERS BASALT

The Sanders basalt covers all the mesas and receives its name from Sanders Mesa in the south-central part of the area. A crescent-shaped belt extends from Nelson Mesa on the east to Black Mesa on the west. The basalt caps the extensive mesas far to the west, north, and northeast beyond the mapped area.

Along the southern mesas the Sanders basalt rests directly on the rhyolite tuff beds of the Gila(?) conglomerate (pl. 1*A*), but to the north it was poured out over the Wilder formation or Gila(?) conglomerate. Along the eastern margin of Bozarth Mesa flows of the Sanders basalt interfinger with lava flows of the Wilder formation. Beneath the small mesa north of Nelson Mesa a thin flow of Sanders basalt overlies the rhyolite tuff, and, in turn, is covered by 50 feet of Gila(?) conglomerate over which a second flow of Sanders basalt was poured. At one place on Nelson Mesa the Sanders basalt lies directly on the older bedrock surface. Along the south and east edges of Centipede Mesa, the Gila(?) conglomerate beneath the Sanders basalt is very thin, indicating that locally the lava encroached on the older bedrock farther east and south.

The individual flows of lava are thin, ranging from 5 to 50 feet in thickness. As many as seven flows may be counted along the mesa walls. Usually the top flows have been so eroded that the original thickness cannot be determined, but at the west edge of Copper Creek Mesa, where Gila(?) conglomerate is present on top of the basalt 200 feet of Sanders basalt is exposed. On Nelson Mesa, however, where two patches of Gila(?) conglomerate remain on top of Sanders basalt, only about 50 feet of basalt is exposed. However, it is probable that additional flows formerly covered the younger Gila(?) conglomerate. Along the west wall of Bozarth Mesa a relief of almost 100 feet is indicated for the erosion surface antedating the Sanders basalt, and as a result there is some variation in thickness of the Sanders basalt.

The Sanders basalt is grayish black and contains conspicuous laths of plagioclase separated by microscopic crystals of olivine and augite. The size of the grains ranges from fine to very fine. Thin sections reveal that the texture is subophitic; euhedral crystals of labradorite are separated by crystals of purplish, weakly pleochroic augite, locally in ophitic intergrowth, and coarser crystals of olivine partly altered to iddingsite. Magnetite is an important accessory mineral. Intersertal textures are rare and consist of black opaque glass separating the labradorite crystals. Coarse vesicles are common, particularly in the upper and lower few feet of each flow. Locally, the vesicles are concentrated in small vertical pipelike forms, 1 or 2 feet high and several inches in diameter. They may enlarge in cross section near the top of the flow. Calcite amygdules are common, and where the lava has been fractured, calcite veins occur. Quartz xenocrysts are present in the Sanders basalt north of Butcher Corral Point; possibly they have been derived from the underlying Lawler Peak granite.

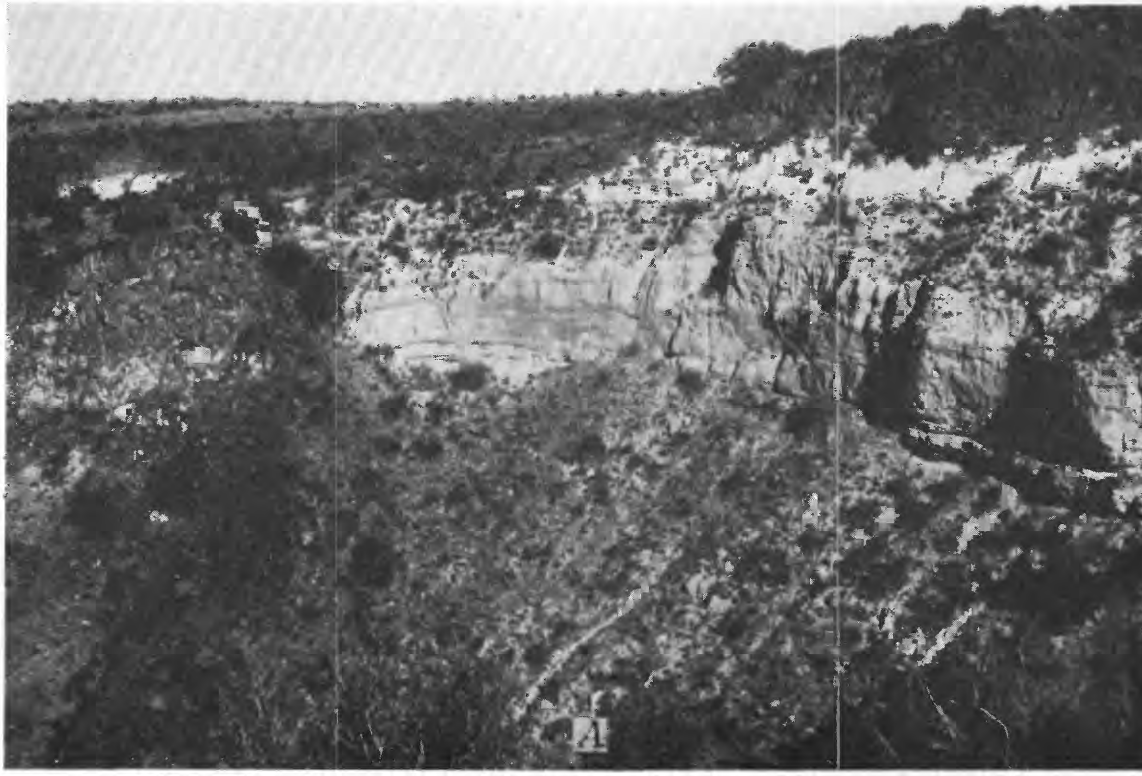
ORIGIN OF THE GILA(?) CONGLOMERATE AND ASSOCIATED VOLCANIC ROCKS

Before Gila(?) time, an erosion surface was formed somewhat comparable to the present erosion surface except that there were no mesas. The total relief was apparently greater at that time, because the filled canyons have not been completely exposed by present streams. The region of lowest elevation was to the west of the Bagdad area, where now there are extensive mesas. The main streams of the region probably flowed south and west, as Burro and Boulder Creeks now flow. Along the main canyons, now the sites of Bozarth Mesa and the mesa east of Wilder Creek and to the north of the mapped area (pl. 3), volcanoes erupted, building cinder cones and pouring out lava flows. The volcanic material blocked the streams, and sediments accumulated in the canyons. New cinder cones and additional lava flows accumulated on the sediments. The cinder cones were easily eroded, and the pyroclastic material was deposited nearby, forming the water-deposited horizontally bedded tuff of the Wilder formation. Finer sediments and limestone accumulated in ponds. The tributary canyons, such as the one now buried beneath Nelson, Sanders, Copper Creek, and Black Mesas, were dammed by the mixtures of volcanic material and sediments accumulating in the main canyons, and these tributary canyons became filled with local debris, entirely nonvolcanic in character.

At some place upstream, presumably to the north or east, some volcanoes erupted rhyolitic lapilli and ash that were swept down and deposited as thin beds of water-deposited rhyolite tuff. When the pre-Gila(?) canyons were filled by a considerable accumulation of volcanic and sedimentary material, a broad channel along the southern margins of the these valleys was filled with a broad but thin blanket of water-deposited rhyolite tuff. Channels in this blanket account for the difference in the thickness of the rhyolite tuff, and of the Sanders basalt accumulated on the tuff. Early eruptions of Sanders basalt would explain the interfingering basalt flows of the Wilder formation and Sanders basalt to the north. The Sanders basalt must have been very fluid at the time of eruption, if judged by the subophitic texture, coarse vesicular structure, and thinness of flows, and the source could have been some distance to the north or to the east. In contrast, the flows of the Wilder formation appear to have been discharged locally, at least in part. During and after the outpouring of the Sanders basalt, additional sediment was deposited, partly in ponds where limestone accumulated. There is no evidence to suggest that Lawler Peak or the country to the south of the mesas were buried by the Gila(?) conglomerate and associated lava flows, but such evidence may have been removed by erosion.

ROCKS OF PLEISTOCENE TO RECENT AGE

Several terrace deposits consisting of gravels and sands occur along the major streams. The elevation of these terraces ranges from 30 to 80 feet above the



A. GILA(?) CONGLOMERATE AND RHYOLITE TUFF BED (WHITE) COVERED BY SANDERS BASALT.

Along western margin of Sanders Mesa; to the left Sanders basalt is faulted against Gila(?) conglomerate.

B. PLUG OF BASALT OF THE WILDER FORMATION INTRUDED INTO GILA(?) CONGLOMERATE, BOULDER CANYON.

Rhyolite tuff bed (white) near the top and to the right; Sanders basalt forms rim of canyon wall.

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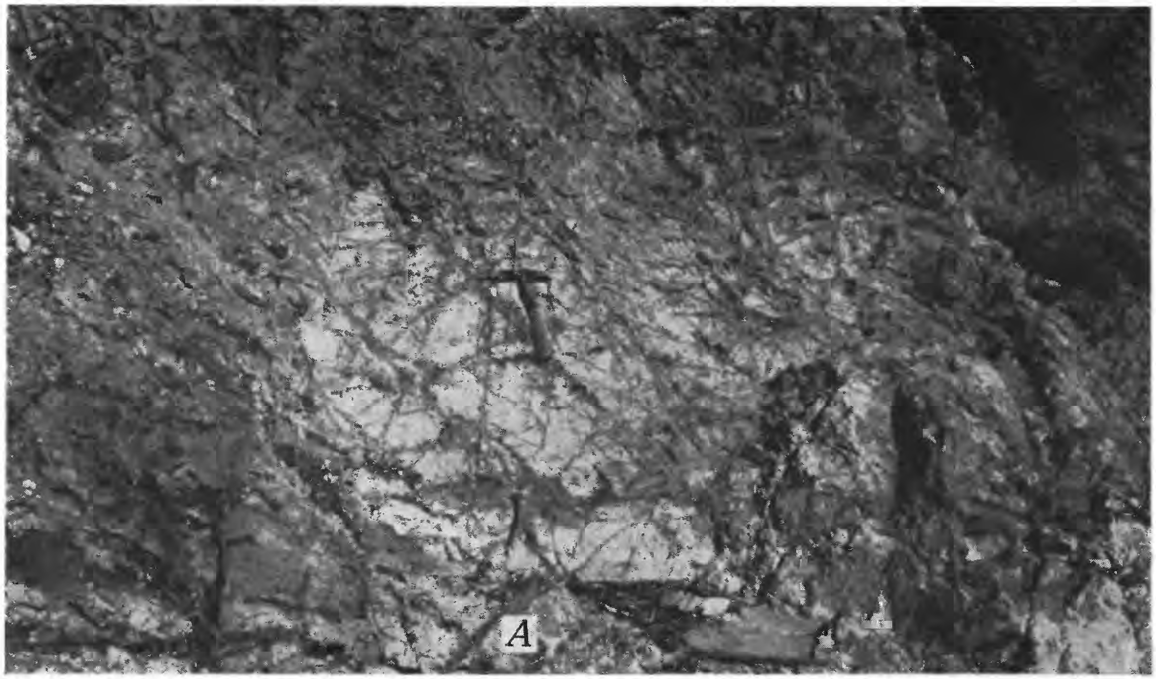


A. FRACTURED AND MINERALIZED QUARTZ MONZONITE, COPPER CREEK.

B. BRECCIA DIKE IN BUTTE FALLS TUFF, BOULDER CREEK, WEST OF BUTTE FALLS present stream channels. Along Alum Creek, a few terrace remnants, too small to be shown on plate 3, are heavily impregnated with iron oxide. Along Copper Creek, below the junction with Mineral Creek, small patches of terrace gravels are cemented with chrysocolla and malachite.

Recent sediments mapped as alluvium include some alluvial-fan deposits along the east bank of Copper Creek south of Black Mesa, and east of Boulder Creek, and south of the Hillside mine. Basin deposits, found in depressions caused by recent faulting, and landslides, such as occur along the eastern margin of Bozarth Mesa, are mapped as alluvium. South of Nelson Mesa along Bridle Creek flood-plain deposits blanket the readily weathered quartz monzonite. Along the lower course of Boulder Creek a moderate amount of river wash is included with the alluvium. The deposits range in texture from boulders to silt and are comparatively thin, mostly less than 20 feet thick, except in some of the alluvial fans.

Along the steep mesa walls, basalt blocks of the Wilder and the Sanders have moved down the slopes as the valley walls have been eroded and lateral support has been removed. Such slump blocks are particularly common along the southern margin of Copper Creek Mesa where they cover the underlying rhyolite tuff. Landslide blocks were mapped along the eastern margin of Bozarth Mesa and northern margin of Centipede Mesa. Some doubt can be raised about the position of much of the Sanders basalt on Black Mesa. Much of the rock is definitely in place, but a part has undoubtedly moved recently down the slopes. It is difficult in many of the exposures to be certain of slide movement. The situation is favorable for sliding, for the lava flows tilt westward and rest on the Gila(?) conglomerate that is easily eroded.

STRUCTURE

STRUCTURE OF THE YAVAPAI SERIES

Only a comparatively small area of Yavapai series has been mapped, and many igneous bodies are present; therefore the evidence for unraveling the structure is fragmentary. In the southern half of the area, a major northeast-trending syncline having an overturned western limb (pl. 5) is suggested by the two belts of the Bridle formation, if the simplest assumption is correct: that these two belts were connected before faulting and igneous intrusion. The northern outcrops of Butte Falls tuff and Hillside mica schist indicate the western limb of a north-trending syncline that is not overturned. The trace of the axial plane of the syncline cannot be located and may be in the area now occupied by granite.

At the southern border of the area, a fault (the ancestral Mountain Spring fault) separates the structurally discordant Butte Falls tuff and Hillside mica schist (pl. 4, *D–D′*). The usual features, such as gouge, crushed rock, and slickensides, are absent; apparently movement along the fault preceded metamorphism and these features were destroyed during the process. The Mountain Spring fault, which is younger than the Lawler Peak granite and marked by gouge and crushed rock, separates the Butte Falls tuff on the east from the Dick rhyolite. To the north, less than a mile southwest of Bagdad, King Peak rhyolite separates the Bridle formation and Butte Falls tuff (pl. 3). The structural discordance between the Bridle formation and the Butte Falls is interpreted to be a result of faulting before the intrusion of the rhyolite. An unconformity would give the same structural discordance, and this possibility cannot be dismissed. The Butte Falls tuff in this small area is not the quartz-sericite schist exposed near the base of the section to the north, but consists of the quartz-feldspar-biotite schist that occurs stratigraphically higher. Furthermore, the contact between the Bridle formation and Butte Falls tuff, now occupied by the King Peak rhyolite, has the same trend and appears to be a northern extension of the ancestral Mountain Spring fault at the southern border. Although this is not proof that a fault separated the Bridle formation and Butte Falls tuff southwest of Bagdad, it lends support to that assumption. The younger Mountain Spring fault follows the inferred extension of the older fault for part of its course.

A fault older than the King Peak rhyolite, and transverse to the structure of the Bridle formation, is inferred west of the Mountain Spring fault where King Peak rhyolite was intruded almost at right angles to the strike of the Bridle formation (pls. 3 and 5). Farther north, the discordance between the northeastward-trending beds of the Bridle formation and northward-trending beds of Butte Falls tuff and Hillside mica schist requires a fault separation, such as the hypothetical transverse fault joining the Bozarth and Hawkeye faults as indicated on plate 5. Perhaps a northwest continuation of the fault older than the King Peak rhyolite west of and parallel to the Mountain Spring fault would explain the discordance.

In the southern half of the Bagdad area, east of the Mountain Spring fault (pl. 5), the Hillside mica schist is acutely folded, in contrast to the more regular structural trends farther north. This acute folding may have resulted from the application of orogenic stresses, from the forceful intrusion of the younger igneous rocks, or from a combination of the two. In general, the folded structures of the mica schist are discordant to the igneous contacts. In other regions where deformation of intruded rocks is related to emplacement of igneous masses, the intruded rocks show better conformity with intrusive contacts than is shown at Bagdad. Moreover, the mica schist is acutely folded in the easternmost exposures, although little granite crops out. The strike of the minor fold axes east of the southeastern belt of the Bridle formation is essentially parallel to the strike of the bedding in the mica schist along the northwestern margin of the belt (pl. 5). This suggests a possible connection between the two masses of mica schist before faulting, and implies that the acute folding occurred before faulting, as well as before igneous intrusion. Furthermore, the northern exposures of Hillside mica schist intruded by the Lawler Peak granite show no apparent deformation related to the intrusion of the granite. However, it cannot be denied that in the south-central part of the area, where the Hillside mica schist was repeatedly invaded by magma, blocks of schist may have been rotated and twisted during intrusion of magma, even though folding by orogenic stresses may have preceded the igneous activity.

Less than a mile southeast of Bagdad (pls. 3 and 5), the Butte Falls tuff is exposed beneath Hillside mica schist. Little can be learned of its structure, owing to the massive character of the tuff probably induced by the metamorphic action of the adjacent Lawler Peak granite. It is assumed that the tuff crops out in the crest of a small anticline.

The two masses of Hillside mica schist separated by belt of Bridle formation in the southeast corner of the area may have been connected before faulting, as suggested. East of the belt the strike of minor fold axes in the mica schist is northwest, and to the west of the belt the strike of the beds in the schist is north and northwest. The Bridle formation strikes northeast. Unless a very complicated fold structure was present before the faulting that moved the Bridle formation in juxtaposition to the Hillside mica schist, the two formations must have been structurally discordant before the faulting. The regularity of the trend of the Bridle formation does not suggest such a complicated fold structure.

One possible interpretation is that the Hillside mica schist was moved over the Bridle formation as a thrust plate in a low-angle thrust, and that the contorted bedding in the Hillside mica schist in the southern part of the Bagdad area represents acute deformation of incompetent rocks near the sole of such a thrust. Later, this hypothetical thrust plate of Hillside mica schist could have been dropped along steep normal faults in contact with the western and eastern belts of the Bridle formation, a sequence of events comparable to the structural history of the Roberts Mountains of Nevada (Merriam and Anderson, 1942, p. 1714).

The evidence indicates that two essentially parallel faults separated the southeastern belt of the Bridle formation from Hillside mica schist, and that subsequently diabase, gabbro, and granite were intruded along these faults (pl. 5).

For the pre-Cambrian structural history, evidence proves fairly conclusively the existence of folded structures. These were broken by several faults along which younger igneous rocks were intruded. Folding probably preceded faulting, although the inferred transverse fault in the southwestern belt of the Bridle formation may have formed during folding. Of most importance is the fact that folding and faulting took place before the intrusion of King Peak rhyolite, the first of a series of intrusive rocks culminating in widespread granite and associated aplite-pegmatite.

STRUCTURE OF THE LAWLER PEAK GRANITE

In the northeastern exposures of the Lawler Peak granite the orthoclase phenocrysts show some planar orientation, and the measurements are plotted on plates 3 and 5, but no linear arrangement of the long axes was noted. The phenocrysts are not oriented uniformly, and the plotted measurement may apply only to a small area; orientation may be lacking in the adjacent granite. As mentioned earlier, the crystals were oriented by flowage before complete crystallization of the granite magma. Although there are some departures, this flow structure generally trends north, and dips vertically or steeply to the west; the strikes are essentially parallel to the strike of the adjacent Hillside mica schist, but the dips are reversed. The aplite dikes in the western part of the granite exposures have a general easterly trend and steep dips essentially at right angles to the flow structure; these dikes may have been injected along lines of tensional stress that correspond to Cloos' cross joints (Balk, 1937, p. 30). Other aplite dikes (pl. 3) trend northeastward or northwestward, and these may have followed primary diagonal joints representing shear planes developed in the consolidated granite. Locally some parallelism exists between the diagonal aplite dikes and neighboring flow structure as in the southeastern part of the granite mass, but this may be just a local variation in the flow structure and may have no relationship to the later shear stress.

Conspicuous joints cut the Lawler Peak granite in the western part of the northeastern mass (pl. 5), and these generally trend eastward, but in detail, two sets of intersecting joints can be recognized, one set strikes N. 75° W., and the other strikes N. 85° E. The dip of both sets is 75° N. Some of these joints contain a little muscovite, indicating that they are primary, and they cut some of the aplite dikes. The aplite dikes, generally, are parallel to the joints, except for local departures. South of the White Spring fault, a conspicuous joint system has an east strike and a vertical dip. The joints are cut by less conspicuous joints that strike northeastward and northwestward (pl. 5). Presumably the joints that strike in a generalized east direction were formed by tension (cross joints), but the other joints may have been formed by shearing stress. Weathering has accentuated these joints, and huge monoliths of unjointed granite rise between the deeply etched joint surfaces.

It can be postulated that the crystallizing granite magma was subjected to east-west compression that caused the local planar orientation of the orthoclase phenocrysts at right angles to the direction of this stress. The compressive stress continued after consolidation of the magma and resulted in the opening of the east-trending tension fractures and northeastward and northwestward-trending shear fractures, some of which were occupied by aplite dikes. Whether or not the stress originated within the granite mass is debatable, owing, in part, to the lack of information on a regional scale. Along the western margin of the Bagdad area, foliation and lineation in the Lawler Peak granite and the gabbro are parallel, despite an oblique angle of contact, and if these structures were also formed by shearing stress, the parallelism of the foliation to the diagonal trend of the aplite dikes is significant. This would indicate that the east-west compressive stress was regional in character.

METAMORPHIC STRUCTURES IN PRE-CAMBRIAN ROCKS

Thermal metamorphism, especially in rocks adjacent to the Lawler Peak granite, has been important in the Bagdad area. In addition, some of the igneous rocks older than the granite are now foliated schists and gneisses, and locally the Lawler Peak granite is gneissic; these foliated structures indicate dynamic metamorphism. Apparently the history of dynamic and thermal metamorphism was long and varied, although most of the observed metamorphic effects probably originated during the emplacement of the Lawler Peak granite.

Evidence of dynamic metamorphism is best displayed in the western half of the area, where foliation in the King Peak rhyolite and the alaskite porphyry is local, but essentially parallel to the more pronounced foliation in the western mass of gabbro. This mass of gabbro is not uniformly foliated; in many exposures of granular rock, hornblende in place of augite is the only indication of metamorphism. Some narrow zones of gabbro, however, have been recrystallized to fine-grained hornblende schist. Foliation in the southwestern belt of the Bridle formation is parallel to that in the adjacent intrusive rocks. The local foliation in the Lawler Peak granite is parallel to the foliation in the adjacent gabbro.

In the northern exposures of Butte Falls tuff, foliation is essentially parallel to bedding, but in the adjacent Hillside mica schist some foliation cuts across the noses of minor folds (amplitude, 6 inches to 2 feet). Elsewhere in this area of mica schist foliation is parallel to bedding in the more micaceous beds, whereas in adjacent beds foliation is discordant with bedding. In the southeastern belt of the Bridle formation, foliation in the lavas is absent or poorly developed except for local bands discordant with the strike of the lava flows (pl. 5). The interbedded tuffaceous beds, however, have a foliation parallel to bedding.

The granodiorite gneiss is poorly foliated and contains some granular facies. The attitude of the gneissic foliation is not uniform but generally is parallel to the schistose structure in the adjacent Hillside mica schist.

The local foliation in the igneous rocks suggests that the dynamic metamorphism is related to shearing stress and that the foliation planes are essentially surfaces of slip (Turner, 1948, p. 277). Perhaps the bedding foliation in the northern exposures of Butte Falls tuff and Hillside mica schist and in the tuffaceous sediments interbedded with the Bridle formation can be explained on the basis that the bedding planes offered the least resistance to the shearing stress and became surfaces of slip (Turner, 1948, p. 176).

Products of thermal metamorphism are found in the south-central part of the Bagdad area, where Lawler Peak granite has intimately intruded the older rocks. The gabbro and related rocks rarely show foliation, and unoriented coarse crystals of biotite are common. The massive amphibolite in the Bridle formation may be the product of thermal metamorphism. Sillimanite is a common accessory mineral in the Hillside mica schist, and large muscovite crystals, 2 to 5 mm in diameter, have a preferred orientation, in part parallel to the bedding, even where the beds are folded (amplitude, 50 to 500 feet). Many of these large muscovite crystals are poikiloblastic, indicating late growth. The parallelism of the foliation to bedding in these coarse-grained schists can be related to thermal metamorphism as Harker (1932, p. 35–36) suggests:

> The conditions are different in the earlier stages of (thermal) metamorphism of a shale or slate which possessed a marked fissility, due either to bedding-lamination or to superinduced cleavage. As their fissile property attests, such rocks offer much less resistance along the bedding or cleavage than across it. Until this difference is obliterated by total reconstruction of the rock, new minerals are generated and grow in a medium having peculiar mechanical properties. The flakes naturally push their way in the direction of least resistance, and so acquire a regular parallel orientation.

Recrystallization of minerals in parallelism with bedding or other older structures has been called mimetic crystallization (Knopf and Ingerson, 1938, p. 39). The bedding foliation in the Hillside mica schist in the south-central part of the area appears to be mimetic, and follows bedding planes.

In the northern exposures of Hillside mica schist near the Lawler Peak granite, mica crystals range from 0.5 to 1 millimeter in diameter, whereas to the west and farther from the granite, mica crystals in the Butte Falls tuff are small, 0.1 to 0.2 millimeter. Proximity to the granite undoubtedly favored the coarse growth of the mica crystals, but it is not clear whether the coarse crystallization was mimetic and followed older foliation planes and beds, or was contemporaneous with deformation (dynamic metamorphism).

Lineation was observed in the metamorphic rocks, particularly in the foliated gabbro, Bridle formation, Butte Falls tuff, Hillside mica schist, and gneissic Lawler Peak granite. The lineation is exposed on the foliation planes and most of it is marked by alternating streaks of light-colored and dark minerals, the prismatic minerals, principally hornblende, being dominantly parallel to the streaks. In the northern exposures of the Hillside mica schist, lineation is also marked by wrinkling of the foliation planes. Measurements of the plunge, that is, the angle between a horizontal line and the line of lineation as measured in a vertical plane, have been plotted on plate 5. Cloos (1946) has given the most comprehensive discussion on the origin and interpretation of lineation; of the many types recognized by Cloos, the Bagdad occurrences of streaking resemble those produced by flowage or by growth of minerals. These two types of lineation may be parallel or discordant to the major tectonic axes. The lineation produced by wrinkling of the foliation planes in the Hillside mica schist developed after the growth of the coarse mica flakes and its plunge bears no apparent relationship to the plunge of the minor fold axes (pl. 5).

The minor fold axes in the northern exposures of the Hillside mica schist also give a linear structure to the rocks. In the northeastern exposures, these minor fold axes plunge southeast, whereas to the west they plunge northeast. The pattern of these minor folds, with but one exception, is similar, with the beds always offset to the right (pl. 5). If the minor folds with northeast plunge were drag folds formed during the major period of folding, this pattern in association with the north plunge would indicate a major anticline to the east, and the tops of the beds would be to the west. However, well-graded bedding adjacent to some of the minor folds indicates that the tops of the beds are to the east. Moreover, the pattern of the southeastward-plunging minor folds suggests a southward-plunging major anticline to the west and tops of the beds would be to the east, as confirmed by other observations. The possibility of rotation along the Hillside fault cannot be ignored, but in contradiction, a minor fold pattern at the north end of the Butte Falls tuff suggests a major northward-plunging anticline to the west.

Until the plunge of the major fold axes can be determined by more extensive studies in the Bagdad region, the relationship of the minor fold axes and lineation to the major fold axes must remain in doubt. Foliation and lineation may bear no relationship in time and in stress pattern to the major and minor folds but may have formed during the period of metamorphism after the major folding and the intrusion by the igneous rocks.

The southwestward-plunging lineation in the southwest corner of the mapped area contrasts sharply to the northward-plunging lineation in the northern exposures of Butte Falls tuff and Hillside mica schist. Perhaps these lineations were originally geometrically concordant, and were rotated later along some fault. Movement along the inferred northward-trending fault antedating the King Peak rhyolite (ancestral Mountain Spring fault) presumably took place before metamorphism. Southward-plunging lineation occurs east of the Mountain Spring fault at the south margin of the area, and evidence suggests that the Mountain Spring and Hillside faults have been connected; northward-plunging lineation occurs west of the Hillside fault. Thus it is difficult to relate possible rotation to movement along the Mountain Spring fault. Until more information is available relating to the origin of the lineation in the Bagdad area, no reasonable explanation can be given for the opposite plunge of the lineation.

For many square miles, pre-Cambrian granite surrounds the small area of rocks older than the granite exposed at Bagdad. The local gneissic structure in the Lawler Peak granite suggests that shearing stress contemporaneous with and following the emplacement of the granite was responsible, in part, for the foliation and lineation in the intruded rocks. At the time the granitic magma was being emplaced, the rock temperatures of the relatively small mass older than the granite would have been raised, and these rocks could have recrystallized upon the application of shearing stress. The resulting metamorphism would be dynamothermal. However, the process of metamorphism may have been as prolonged and varied as the process of intrusion of magma, and not limited in time to the intrusion of the Lawler Peak granite. In support of this interpretation. flattened and schistose gabbro inclusions are found in the nonfoliated alaskite. Products of early thermal metamorphism may have developed at the margins of the alaskite porphyry, and is suggested by the unoriented aggregates of actinolite containing garnet in the Bridle formation adjacent to alaskite porphyry.

The assignment of the metamorphic rocks in the Bagdad area to zones of metamorphism, such as the chlorite, biotite, and sillimanite zones (Harker, 1932), presents some problems. The highest grade of metamorphism, that of the sillimanite zone, locally is adjacent to the Lawler Peak granite. Some of the slates in the Butte Falls tuff and chlorite-sericite schists in the Bridle formation suggest a low grade of metamorphism, that of the chlorite zone. However, the chlorite in part may represent a retrograde alteration of biotite. The appearance of much biotite, hornblende, and some garnet, and the calcic character of much of the plagioclase suggest the intermediate grade of metamorphism, the biotite or garnet zone which corresponds to Billings' (1937, p. 543) middle-grade zone. Some comparisons with the Littleton-Moosilauke area are worth noting, for Billings (1937) has stated that the higher grades of regional metamorphism are related to adjacent plutonic bodies, a conclusion also reached by Barrell (1921) for the rocks of western Connecticut. Furthermore, Billings has noted that in the higher zones of metamorphism, foliation is parallel to bedding.

FAULTS YOUNGER THAN THE LAWLER PEAK GRANITE

At least three periods of faulting followed the intrusion of the Lawler Peak granite. The first displacement along the White Spring fault occurred shortly after consolidation of the granite and recurrent movement took place after the intrusion of the quartz monzonite, and again after the outpouring of the Sanders basalt. The Mountain Spring and Hillside faults are younger than the granite and older than the quartz monzonite. The Bozarth and Hawkeye faults show the largest displacement of the Gila(?) conglomerate, and recurrent movement on the Hillside fault and several unnamed small faults displaced the Gila(?).

WHITE SPRING FAULT

The White Spring fault has a strike of N. 70° W. and a vertical dip; it has been traced for about 2 miles, almost entirely within Lawler Peak granite. It has a crushed zone as much as 30 feet wide containing brecciated and nonbrecciated fluorite. This fault presumably formed shortly after consolidation of the Lawler Peak granite, and before fluorite deposition that appears to be related to the late stages of Lawler Peak granite igneous activity. Late displacement has occurred.

A north-trending vertical fault containing fluorite is cut off by the White Spring fault; it may be slightly older, or more probably formed at the same time. These two faults may have formed by an upward thrust from the underlying magma below the solidified Lawler Peak granite.

At the east end of the White Spring fault, the quartz monzonite is in fault contact with the Lawler Peak granite, and the overlying Gila(?) conglomerate is not faulted. On the east edge of Nelson Mesa, however, the Gila(?) and overlying Sanders basalt show a 5-foot displacement on the strike extension of the White Spring fault. These data would indicate that recurrent movement took place after the intrusion of the quartz monzonite and again after the outpouring of the Sanders basalt.

MOUNTAIN SPRING FAULT

The Mountain Spring fault, in the southwestern part of the Bagdad area, separates the Bridle formation, Butte Falls tuff, and Dick and King Peak rhyolites from the Lawler Peak granite and Hillside mica schist. The fault was mapped for almost 3 miles and extends south beyond the margin of the area. To the north, the fault is cut off by the quartz monzonite, indicating that the faulting took place after the intrusion of the Lawler Peak granite and before emplacement of the quartz monzonite. The fault has four sharp bends along its course, but a segment has a continuous north strike for more than 1½ miles (pl. 5). The northern strike-extension of this long segment coincides with the strike of a fault older than the King Peak rhyolite and the southern strike-extension coincides with the premetamorphic fault separating the Butte Falls tuff and Hillside mica schist. In part, therefore, the Mountain Spring fault is coincident with an older fault. The dip of the Mountain Spring fault is to the west and ranges from 70° to 75°. If the long segment follows the older fault for 1½ miles, presumably the older fault also dipped westward. Absence of granite on the hanging-wall side immediately west of the fault suggests that the hanging-wall block is the dropped block, and the fault is normal. If it is assumed that the older fault also dipped westward, the older fault may have been a reverse fault, because the younger Butte Falls tuff was displaced against the older Bridle formation. Van Gundy (1946) has reported a similar reversal of movement for faults in the Grand Canyon region. The present displacement along the Mountain Spring fault is the resultant of both the older and younger displacements, where the two faults coincide, but no data are available to give an exact measure.

Along part of the course of the Mountain Spring fault, dikes of rhyolite, diorite porphyry, and quartz monzonite porphyry have been intruded.

HILLSIDE FAULT

The Hillside fault has a general north trend and has been mapped for a distance of about 3 miles. To the north it is lost in the Hillside mica schist, and to the south it dies out in the Sanders basalt. It dips 70° to 80° W., and, as the hanging-wall side is the dropped block, the fault is normal. The Hillside fault is mineralized along much of its length, the Comstock-Dexter and Hillside mines being located along such mineralized parts. As will be discussed further on in the text, the mineralization is related to intrusion of the quartz monzonite, and this dates the age of the fault as older than the quartz monzonite. The strike and dip of this fault are essentially the same as the Mountain Spring fault, and small projections of the strikes of both faults would result in their connection, suggesting that these faults were connected before the intrusion of the quartz monzonite. Recurrent movement along the Hillside fault has displaced the Gila(?) conglomerate and the associated basaltic rocks with a maximum dip-slip component of about 250 or 300 feet, indicated by the displacement of the rhyolite tuff bed of the Gila(?) conglomerate east of the Hillside mine. No data are available to estimate the total dip-slip movement on the fault.

HAWKEYE FAULT

The Hawkeye fault has a north-northwest trend and has been mapped for almost 1½ miles. Throughout much of its course, it is difficult to trace, owing to the poor exposures of quartz monzonite, the principal rock in which it occurs. Several prospect pits sunk along the fault in a search for chrysocolla and malachite deposits have greatly aided in determining the location of this fault. The crushed zone is small, ranging from 1 to 2 feet in width. Except for local departures, the dip is easterly, from 70° to 80°. The Gila(?) conglomerate on the hanging-wall side is locally dropped next to the quartz monzonite; therefore, it is a normal fault. In an adit driven along the fault, slickensides on the fault surface have a rake of 60° S. suggesting that the movement was an oblique slip, and where the Hawkeye fault cuts through the Black Mesa breccia pipe, a southerly strike-slip component is indicated by the 70-foot southerly displacement of the northeastern part of the pipe (fig. 23). The only data available for the dip-slip component are obtained from churn-drill holes; the chalcocite blanket is present on the dropped hanging-wall block and is absent on the footwall side. These data (fig. 21) indicate a minimum dip-slip component of from 250 to 300 feet. If a rake of 60° S. is assumed, the minimum net slip would be approximately 340 feet.

The Hawkeye fault is of considerable importance in exploration for chalcocite ore, owing to the possibility that the fault has not appreciably displaced the chalcocite zone in the quartz monzonite. As will be discussed later in the text, there is ample evidence to suggest that the chalcocite blanket was appreciably displaced and eroded from the footwall side of the fault (fig. 21). Because of the spatial relations of a supposed displaced quartz monzonite porphyry dike exposed in Maroney Gulch, earlier private reports to the Bagdad Copper Corp. suggested that the oblique slip was to the north rather than to the south. However, dikes are frequently arranged en echelon, and the fault is buried beneath the stream gravel in Maroney Gulch, so no proof can be given that the two dike exposures represent faulted segments of the same dike. On the other hand the displacement of the Black Mesa breccia pipe is more convincing evidence for an oblique slip to the south and the rake of the slickensides in the adit adds further evidence for a movement in that direction.

BOZARTH FAULT

The Bozarth fault appears at the east edge of Bozarth Mesa and was mapped for a distance of more than 3 miles. The strike ranges from N. 20° W. to N. 20° E. The dip is steep to the east but very few direct observations can be made of the attitude of the fault surface, owing to cover of talus and alluvial wash. In Boulder Creek, an east dip of 80° was noted. The eastern side is the dropped block, an indication that the fault is normal. Near the north end of the fault the Sanders basalt has been dropped about 400 feet. At the north edge of the mapped area, the displacement is only about 150 feet and at the south end of the fault, the basal contact of the Gila(?) conglomerate is dropped 100 feet.

The southern extension of the Bozarth fault is directed toward the northern extension of the Hawkeye fault, but the area between is covered by thick soil and talus derived from the Gila(?) conglomerate and Sanders basalt; therefore no exposures were found revealing a continuation of the faults. Both are normal faults having steep easterly dips and comparable displacement, so it is probable that the two faults are connected, as indicated by an inferred fault connection shown on plates 3 and 5.

A graben structure is present between the Bozarth normal fault on the west and the Hillside normal fault to the east (pl. 4, *B–B′*). Locally, additional short faults, essentially parallel and to the east of Bozarth fault, have dropped the Sanders basalt to lower altitudes.

SMALL FAULTS

A number of short faults have cut the Sanders basalt, and the displacement of the underlying rhyolite tuff of the Gila(?) conglomerate provides the chief evidence. The largest of these faults is located at the west margin of Sanders Mesa and shows a maximum vertical displacement of 150 feet (pl. 1A). This fault can be traced for about a mile, and no break appears in the rhyolite tuff along the southern margin of the mesa. The fault has a steep dip west and is normal.

A fault of similar magnitude is present in the northeast corner of the area at Urie Spring, a spring which discharges warm water. This fault is not traceable very far to the northwest of the spring but probably could be followed for some distance to the southeast beyond the mapped area.

The other faults are much shorter and show much less displacement, usually less than 50 feet, and the attitudes of fault surfaces are difficult to determine, other than that the dips are steep. The faults east of Bozarth fault have been mentioned in connection with that fault, as they probably are related to it. Along the eastern branch of Wilder Creek, at the northern margin of the Bagdad area, a series of small faults are exposed that offset basalt of the Wilder formation and sediments of the Gila(?) conglomerate. In general, the movement is down 5 to 20 feet on the west side of each fault, but in one fault this offset is reversed.

DEFORMATION OF THE GILA(?) CONGLOMERATE

Some warping and folding of the Gila(?) conglomerate has taken place and is possibly related to the post-Gila(?) faulting. The exposures of the conglomerate are usually too poor for systematic recording of the attitude of the bedding, and such observations might be misleading, owing to the coarse texture of the conglomerate, for crossbedding on a large scale is usually a feature of deposits of this character. However, the fine-textured rhyolite tuff beds of the Gila(?) and the thin flows of overlying Sanders basalt are units that give a clue as to deformation. Presumably, the rhyolite tuff when deposited was nearly horizontal and a surface of low dip is to be expected from the outpouring of fluid lava such as that of the Sanders basalt.

In a shallow structural basin on Nelson Mesa, conglomerate younger than the Sanders basalt has been protected from erosion. The underlying basalt flows and the rhyolite tuff dip eastward at a low angle in the small canyon draining west to Mesa Pass. To the east of this canyon the rhyolite tuff dips more steeply to the west in a definite monoclinal structure (pl. 3). The pre-Gila(?) surface was irregular, as shown by the high area of quartz monzonite surrounded by conglomerate in the northern part of Nelson Mesa, and the deformation here may be due to combination of warping related to the latest faulting and to unequal compaction of the underlying sediments resting on an irregular surface.

Warping of the rhyolite tuff at the southwestern margin of Sanders Mesa apparently is related to the fault along which the Sanders basalt has been dropped on the west side. Copper Creek Mesa has a definite tilt southward that may be related to the Hillside fault. The other good example of warping is on the east end of Centipede Mesa where the structure is almost monoclinal, and this may be due to bending of the block west of the Bozarth fault.

STRUCTURE IN THE BAGDAD MINE

At the time the Bagdad mine was mapped, December 1943 and January 1944, 4 levels, 30 feet apart vertically, were accessible, and on 3 levels, drifts were accessible along the boundaries of 10 stopes driven essentially on the 100-foot coordinate lines as part of the stope preparation for block caving. On the 4th, the lowest or haulage level, drifts connecting the drawpoints made the lower part of the ore body almost completely accessible. A total of 836 fractures showing gouge or crushed rock indicating some movement were mapped and also 367 recognizable quartz veins that had sufficient continuity to determine their attitude. The minute fractures along which the bulk of the sulfides were deposited could not be mapped underground, as only two dimensions could be recognized on most of the drift walls, and lack of continuity of the fractures made it impossible to determine the third dimension. On the surface over the mine, the attitude of many of these minor mineralized fractures could be determined, owing to the irregularities of the outcrop surface and oxidation of the sulfides which clearly showed the trace of the fracture on the outcrop. The attitude of 472 mineralized fractures was determined from points selected at random over the mine.

A convenient method for comparing strikes and dips of many veins and faults is to plot the attitudes on equal-area projection nets, for in this method the three dimensions can be plotted on a two-dimensional diagram. An excellent description of this method is given by Billings (1942, p. 118–122). All observations on strikes and dips of the faults, veins, and minor mineralized fractures at the Bagdad mine were plotted on three equal-area nets projected to the lower hemisphere, and the resulting point diagrams were contoured (figs. 2–4).

Three maxima for the veins are disclosed. The greatest number of veins strike N. 60° E. and dip steeply northwest or southeast. The second maximum has a strike of N. 10° E. and steep westerly dips. The third maximum is at N. 40° W. with steep southwest or northeast dips. Crosscutting relationship indicates that the veins striking N. 60° E. are younger than the veins striking N. 10° E., but no positive evidence could be found relating to the age of the veins striking N. 40° W. Most of the quartz-molybdenite veins have random orientation and flatter dips, as low as 25°, and they are younger than the veins striking northeast. The molybdenite veins are so few in number that they

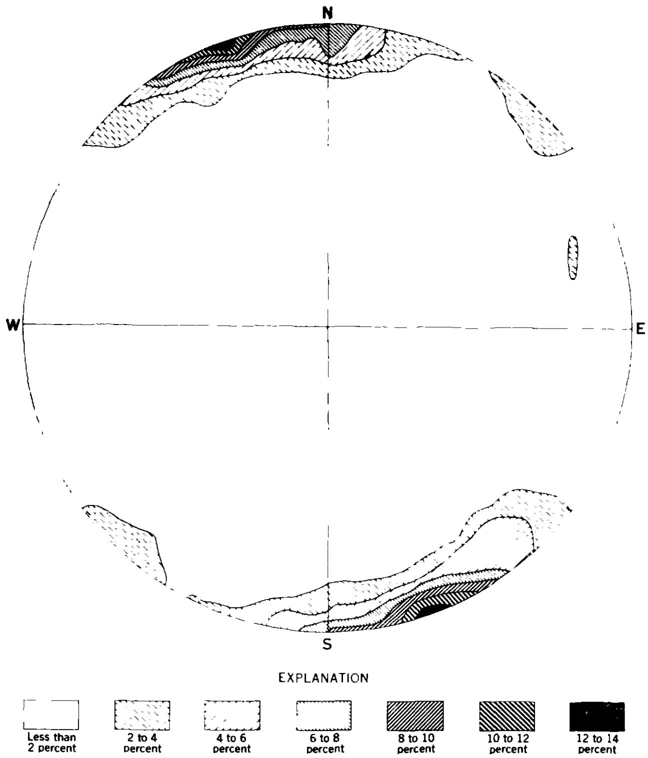


FIGURE 2.—Contour diagram of 836 faults, Bagdad mine. Lower hemisphere projected.

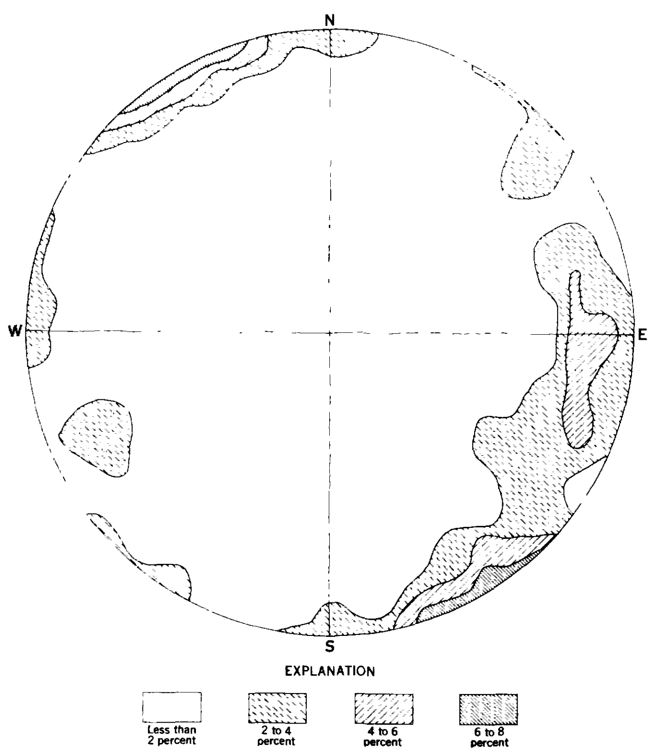


FIGURE 3.—Contour diagram of 367 veins, Bagdad mine. Lower hemisphere projected.

are not shown in the contour diagram (fig. 3). Two wide quartz pyrite-chalcopyrite veins str'ke N. 40° W. and dip 65°–70° SW. and an adjacent aplite dike has the same strike, but a steeper dip, 80°–85° SW. (fig. 18).

The minor mineralized fractures are not set at random orientation, as a casual examinεtion might suggest (pl. 2A), but three maxima stand out on the equal area projection (fig. 4). The greatest number strike N. 70 E. and dip 70° N. The second maximum strike N. 20° E. and dip 75° NW. and the third maximum strike N. 40° W. and dip vertically. In general, a close correlation in attitude exists between the dominant trends of the minor mineralized fractures and the larger veins, except that a northerly dip is recorded for the dominant fractures striking N. 70° E. and steep dips in opposite directions are recorded for the veins striking N. 60° E.

Faults striking northeast are important because of the many having this trend, and because they show the greatest continuity and greatest amount of displacement (fig. 18). The dominant strike is N. 70° E., and the dips range in direction from northwest to southeast. Commonly, these faults follow the veins, in places completely brecciating a vein and in other places follow-

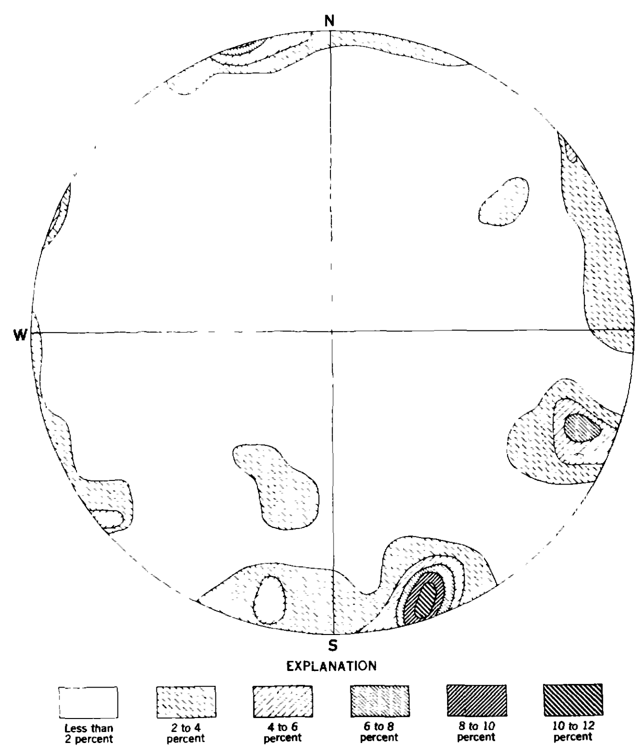


FIGURE 4.—Contour diagram of 472 mineralized fractures, Bagdad mine. Lower hemisphere projected.

ing the hanging wall or footwall of a vein. The faults striking northeast displace the aplite dike (fig. 18), the strongest veins striking northwest, and most of the faults striking northwest. The greatest offset observed was 35 feet where one of the faults cuts the aplite dike, but in 83 percent of 62 observations of intersections of faults striking northeast with older faults or veins, the displacement was 1 foot or less. A few had displacements as much as 5 to 10 feet. The sum total displacement along all faults striking northeast is small; if it is assumed that the strike of the aplite dike is constant, the total eastward displacement is 100 feet, distributed along 12 of the larger faults. An additional displacement of 20 to 30 feet is suggested by the displaced veins striking northwest, indicating that the total eastward displacement through a distance of 1,000 feet was less than 150 feet. Some of the displacements could be explained by dip-slip movement offsetting high-angle faults or veins, but in most intersections a strike-slip component was obvious as faults or veins having opposite dips were offset the same amount and in the same direction. Many slickensides have a rake of 10° to 20° E., coinciding with the observed offsets, an indication that although the net slip was oblique, the strike-slip component was much greater than the dip-slip component. In general the movement along faults striking northeast was to the northeast and down for the block on the northwest side of the fault, regardless of the direction in which the fault dips.

Some faults have a northwest strike, but they are subordinate in number to the faults striking northeast and most of them have no great continuity except in the northwest corner of the Bagdad ore body (fig. 18). Generally the faults striking northeast cut the faults striking northwest, but in a few examples the reverse was noted. The veins striking northwest were reopened by faults that appear to be older than the northeast faults. With one exception where a vein striking northeast was offset 5 feet, most of the displacements along northwest faults are 1 foot or less. Where the slip components can be determined, the strike-slip component was northwest on the northeast side. Generally, the strike-slip component was greater than the dip-slip component.

The period of faulting was largely pre-Gila(?) and older than the supergene enrichment in the Bagdad mine, but in Copper Creek some Gila(?) conglomerate had dropped several feet on the north side of one of the faults striking northeast. The faults striking northeast showed up particularly well in the caved area over the Bagdad mine before the beginning of open-pit mining. The ground caved parallel to the faults, and for several months in 1944 the southern boundary of the caved area was stationary, bounded by a fault striking northeast.

RELATIONSHIP OF MINERALIZATION TO STRUCTURE

The quartz monzonite stocks crop out in a belt 7 miles long with an approximate trend of N. 70° E. (fig. 5). The limitation of these stocks to this belt indicates a fundamental structural control, and the intrusion of the stocks marks the first major episode in the late Cretaceous or early Tertiary structural history. Several small aplite dikes in the central stock at Bagdad trend N. 40° W. The diorite porphyry dikes that cut the quartz monzonite locally have a generalized trend of N. 60° E., though some variation is present, particularly to the southwest, where these dikes, in part, follow the structures in the pre-Cambrian rocks. But where they extend northeast into the massive granite, the dikes are approximately parallel to the general trend of the quartz monzonite stocks. Locally, a north trend is present where the dikes follow older faults. Although no direct evidence is available, by analogy with the usual sequence of rock types in and around centers of igneous intrusion, the inference is drawn that the aplite dikes are older than the diorite porphyry dikes. The diorite porphyry dikes are cut by the quartz monzonite porphyry dikes, which have a generalized trend of N. 20° W., but, owing to the scale used in field mapping and the nature of the exposures, no measurable displacements were proved. The quartz monzonite porphyry dikes are cut by pyrite-chalcopyrite-galena veins in the southern part of the area, indicating that the dike swarms were intruded before mineralization in the Bagdad area.

Trends of structures

N. 60°–70° E.	N. 40° W.	N. 20° W.	N. 10°–20° E.
Stocks	Aplite dikes		
Diorite porphyry dikes		Quartz monzonite porphyry dikes	
Veins	Veins		Veins
Minor fractures	Minor fractures		Minor fractures
Faults	Faults		

The prevailing northeast and northwest trends of the faults, veins, and minor fractures in the Bagdad mine are essentially parallel to the structural trends related to the quartz monzonite stocks and associated dikes, as shown in the accompanying tabulation.

The angular difference of 20° between the N. 20° W. dikes and N. 40° W. structures, is not great, and presumably these two trends represent essentially

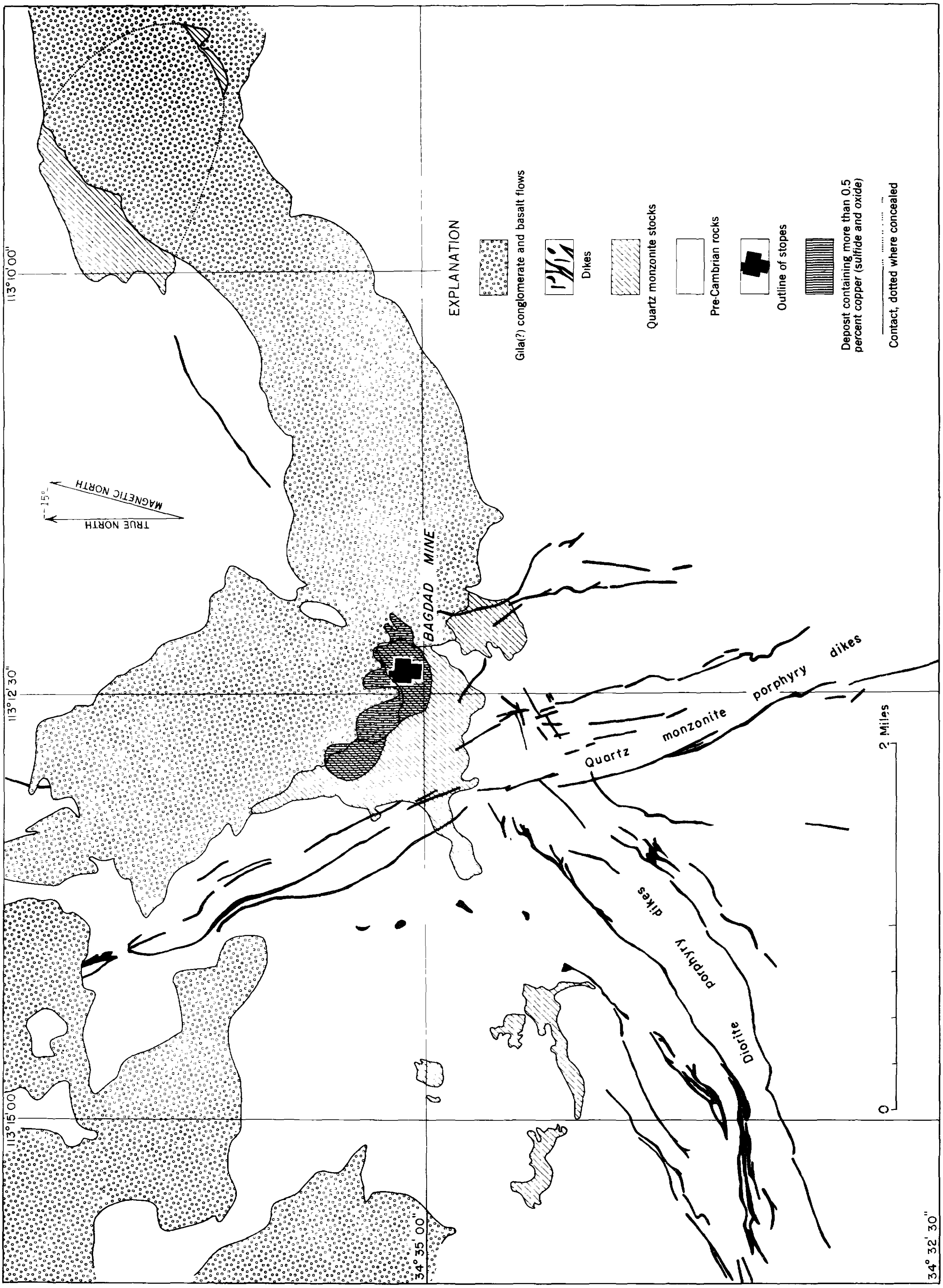


FIGURE 5.—Sketch map showing dike intersections at the mineralized stock, Bagdad mine, Bagdad, Ariz.

parallel structures. However the N. 10°–20° E. trend of one set of veins and mineralized fractures is not represented by any of the older or younger larger structures.

Only the northeast-striking faults yield positive evidence of the character of rupture, and as stated above, the movement has been east and slightly down on the north side of the faults, indicating that faulting took place as a result of a nearly horizontal shear couple, and the north side moved east relative to the south side. It might be inferred that the earlier parallel fractures occupied by northeast veins, diorite porphyry dikes, and quartz monzonite stocks formed also from a horizontal shear couple.

The suggestion might be offered that the fractures striking northwest, particularly those occupied by the aplite dikes and the wider veins striking northwest were formed by tensional stress, but no direct evidence was found to support this interpretation. The fact that some of the faults striking northwest have an oblique-slip movement, up and to the northwest of the block on the northeast side of the fault suggests another essentially horizontal shear direction. Furthermore, the general alternation of rupturing first in one quadrant, then in the adjacent one, does not suggest tension in the northwest quadrant, but rather infers that it was a zone secondary shear, the two quadrants of rupture representing conjugate shears in which the strike-slip component is greater than the dip-slip component.

If the structures striking northeast and northwest are conjugate shears, it is possible that the veins striking N. 10°–20° E. and minor fractures represent reverse faults, and all sets of rupture would be a single "strain system" with nearly east-west relative shortening.

Hulin (1945) has suggested that shrinkage after cooling and crystallization is responsible for the minor fracturing in the porphyry copper deposits, and Locke (1933, p. 623) has emphasized the possibility that shrinkage during mineralization is an important factor. In discussing the Ajo deposit, Gilluly (1942) considered these possibilities and added, as another, collapse owing to escape of magma or volatile constituents from a lower zone or to volcanic explosions that overcame the pressure of the cover rocks; however, he concluded that the ultimate cause of brecciation in the Ajo deposit could not be determined from the present information. Pennebaker (1942, p. 130), in discussing the Ely porphyry copper deposit, made the pertinent comment that if shrinkage on cooling is responsible for the fracturing, all the porphyry bodies at Ely should be fractured similarly, whereas only the porphyry that is within the ore zone is broken. He concluded that tectonic activity was the fundamental cause of minor fracturing in the Ely deposit. Butler and Wilson (1938b, p. 74) pointed out that the fractures striking northeast at Morenci determined the paths along which the porphyry stocks were intruded and that continuation of stresses produced breaks in the stocks of solidified porphyry that are now occupied by veins. They suggested that the minor fractures might be grouped into a definite system if mapped in detail.

If shrinkage after cooling and crystallization was of paramount importance in producing the minor fractures at Bagdad, the other stocks in the same area should be expected to show the same kind of fracturing, and because they are unfractured and also unmineralized, serious doubt exists as to the validity of this explanation for fracturing of the Bagdad deposit. The pattern of these minor fractures is essentially parallel to the pattern of the other structural features, such as the dikes, veins, and faults, and suggests tectonic stresses as the ultimate cause of fracturing. However, the fewer quartz-molybdenite veins which are unoriented, in places having low dips, occupy fractures that may be due to some other cause, such as subsidence after mineralization.

From a broader view, the intersection of the two shear zones, graphically illustrated by the intersection of the dike swarms (fig. 5), is probably of greatest importance in marking the favorable zone of copper deposition. If this interpretation is correct, no prospecting targets for new ore bodies of the porphyry copper type are indicated in the Bagdad area. This conclusion is supported by a lack of any visible signs of appreciable copper mineralization in the other exposed stocks.

The faults in the Bagdad mine were of considerable importance in controlling supergene enrichment, a topic that is discussed in greater detail on page 64. It should be emphasized here that the largest quantity and highest grade of ore occurs where intersecting or closely spaced faults have increased permeability.

The Hillside and Mountain Spring faults may have exerted a broad control in the distribution of the gold-silver-lead-zinc-copper deposits of the area, for these deposits are limited essentially to a northward-trending zone 2 miles wide and these faults are in the middle of the zone. The Hillside fault is mineralized at the Hillside and Comstock-Dexter mines. The Mountain Spring fault is mineralized at the Mountain Spring mine. The Cowboy mine is out of the zone, about 3 miles to the east of the Mountain Spring fault. Many of the small prospects are along narrow quartz veins that have a trend generally parallel to the quartz monzonite porphyry dikes, but have some divergence to the north and east of north. Presumably, these fractures were formed similarly to those occupied by the dikes.

BRECCIA PIPES AND DIKES

GENERAL CHARACTERS

Breccia pipes and breccia dikes are limited to a zone about 2 miles wide and 6 miles long, extending from Grayback Mountain north-northeast to Boulder Creek north of Butte Falls. The pipes and dikes occur in the same general area and are undoubtedly related in origin as the same rocks are found in both. Only the breccia dike west of Butte Falls could be shown on plate 3, because the others are poorly exposed; this dike is in and parallel to the structure of the Butte Falls tuff, and it might be properly termed a "breccia sill." The trend of the zone containing the pipes is approximately N. 30° E., discordant to the prevailing structural trends of the Bridle formation and to those of the younger intrusive rocks—rhyolite, alaskite porphyry and quartz monzonite.

The pipes are not uniform in size and form (fig. 6); some are elongate, measuring 2,000 feet or more by 500 feet. The long axes range in strike from northwest to to east. One pipe is crescent shaped. The smaller pipes are only 100–200 feet in diameter. None are circular in plan.

The ages of the pipes and dikes differ. To the south, three pipes on the east side of Grayback Mountain are older than the Grayback Mountain rhyolite tuff that rests directly on the breccia pipes and is not brecciated. To the north, some of the pipes contain brecciated quartz monzonite porphyry, the youngest of the igneous rocks of Late Cretaceous(?) or early Tertiary(?) age, but unbrecciated quartz monzonite intruded other pipes. Still other pipes contain brecciated rhyolite; the pipe on the west side of Boulder Creek is largely such material. In some pipes diorite porphyry is fragmented, and in others it forms unbrecciated dikelike intrusions. In general, it is evident that the southern pipes are older than the northern pipes, except the rhyolite-breccia pipe on the west side of Boulder Creek.

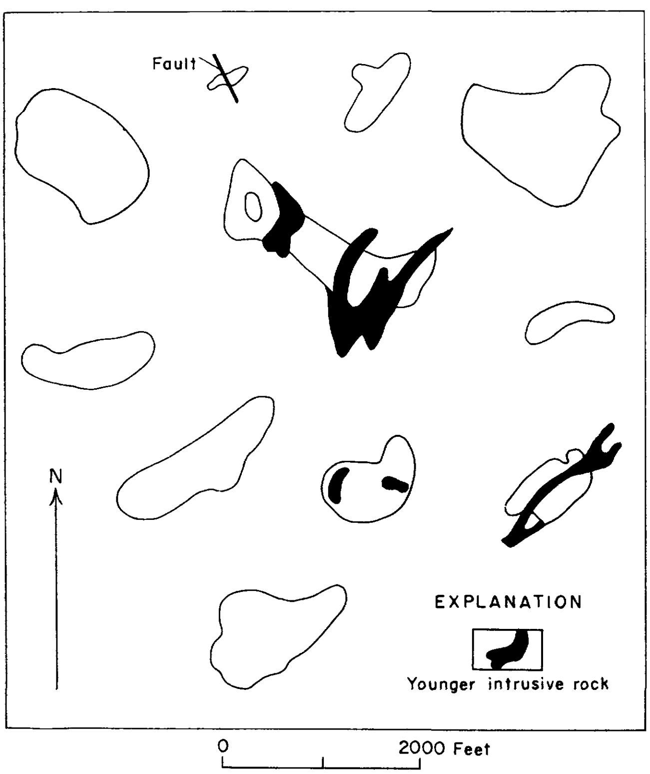


FIGURE 6.—Sketch map showing the variation in outline and size of breccia pipes, Bagdad area, Arizona.

Some of the pipes contain several varieties of rock fragments different from the enclosing rock, and in others the enclosing rock is the dominant rock in the pipe. This difference is shown on the geologic map (pl. 3). In the large pipe along the northern course of Niagara Creek, it is possible to trace through the pipe the surrounding unbrecciated rock units—Bridle formation, King Peak rhyolite, alaskite porphyry, rhyolite, and quartz monzonite porphyry. In places these rocks in the pipe are more crackled than brecciated, although in the main mass of the breccia pipe, fragments of quartz monzonite porphyry 8 to 10 feet across occur a short distance from the crackled dike. This pipe is very permeable and the appreciable openings between fragments are partly filled with crystals of vuggy quartz. The boundary of the breccia is not sharply defined, and quartz veins extend a short distance outward from the pipe. In the center of the pipe there is a mass of unbrecciated King Peak rhyolite. To the southwest a smaller breccia pipe has some similar characters, in that the rock units can be traced through the pipe, but it is less permeable because the fragments are packed more tightly. Moreover, it contains two plugs of quartz monzonite porphyry that, although not brecciated, are highly altered, the biotite phenocrysts are changed to muscovite, and the groundmass to coarse sericite.

The Black Mesa pipe, occurring in the quartz monzonite south of Black Mesa, is one of the smaller pipes, less than 500 feet long, and is composed almost entirely of quartz monzonite fragments averaging about 9 inches across but ranging from 1 inch to 3 feet. This pipe has a sharply defined margin with the unbrecciated quartz monzonite, it is also very permeable, and vuggy quartz appears in the openings containing pyrite, chalcopyrite, and molybdenite. At the southeast corner of the pipe the enclosing quartz monzonite is silicified by closely spaced quartz veins half an inch to 1 inch wide, most of which strike N. 80° E. and dip vertically, but a few are arranged horizontally.

The rhyolite breccia pipe on Boulder Creek is composed almost entirely of angular fragments of white rhyolite, rather closely packed. To the south, adjacent to the main rhyolite pipe, are two small areas of breccia composed of gabbro and fine-grained granite, and many of the fragments are well rounded, indicating considerable abrasion and movement. No granite is exposed nearby which implies that the fragments moved upward. A small area of brecciated Butte Falls tuff is exposed at the southeast corner of the rhyolite breccia pipe. A small mass of unbrecciated flow-banded rhyolite has an intrusive contact with the gabbro-granite breccia, indicating that the latter was formed before the intrusion and brecciation of the rhyolite. The rhyolite breccia pipe is cut by an unbrecciated dike of basalt related to the younger volcanic rocks.

The large breccia pipe near the headwaters of Niagara Creek consists of fragments of King Peak rhyolite and the Bridle formation in a heterogeneous mixture, but the quartz monzonite porphyry dike that cuts the pipe is only slightly brecciated, and its course through the pipe can be mapped. In the large breccia pipe a quarter of a mile to the southeast the fragments are packed more tightly and correspond in character to the enclosing rocks. Unbrecciated quartz monzonite separates the northern tip from the rest of the pipe but on the west side, quartz monzonite is brecciated.

Half a mile to the southeast of the Mammoth prospect a large northwestward-trending elongate pipe consists almost entirely of tightly packed fragments of normal alaskite porphyry, whereas the enclosing rocks are the Bridle formation and the fine-grained facies of the alaskite porphyry. Apparently the fragments were derived from an underlying mass of alaskite porphyry. At the eastern margin of this pipe, brecciated rhyolite containing some foreign fragments, is cemented by unbrecciated rhyolite. The pipe is cut by 3 dikes of rhyolite and 2 dikes of diorite porphyry, and also by a small plug of quartz monzonite, all unbrecciated. To the east, dikes of brecciated rhyolite are present. To the west, another large breccia pipe appears in alaskite porphyry and the fragments are of this rock. Much of the alaskite porphyry is only shattered and crackled, but local masses of breccia contain well-rounded alaskite porphyry fragments, indicating that some movement and abrasion occurred.

The large pipe north of Grayback Mountain consists largely of tightly packed alaskite porphyry fragments. Large masses of the enclosing alaskite porphyry locally containing diabase dikes are only shattered, so that the dikes can be followed for short distances. Small tongues of breccia penetrate the shattered rock. An unbrecciated diorite porphyry dike cuts the pipe.

The breccia dike (or sill) along Boulder Creek consists largely of angular fragments of Butte Falls tuff (pl. 2 *B*), but some rhyolitic and granitic fragments are present. The dike is cut off to the north by the rhyolite breccia pipe and associated pipe of Butte Falls tuff; this would imply that the breccia dike is older. Near the rhyolite breccia pipe, the dike is 4 feet wide, but it narrows to the south to 3 feet where it crosses Boulder Creek and to 2 feet or less farther south. At the south end of the dike, the fragments are mostly 1 inch or less, but at the north end, fragments as large as 8 inches are present, and rounded "cobbles" are common. Presumably the breccia dike is related genetically to the rhyolite and associated breccia pipes and represents the first stage of activity in breccia formation. The granitic fragments indicate some upward movement of the material in the dike.

The other breccia dikes were too poorly exposed to trace them in mapping, but they are associated closely with the rhyolite and diorite porphyry dikes in the southwestern area. The breccia dikes in that area average about 1 foot in width and parallel the younger igneous rocks. Diorite porphyry and rhyolite fragments are found in these breccias, and dikes of younger diorite porphyry are in intrusive contact with the breccia dikes.

In summary, the breccia pipes occur only in the western half of the area and differ in size and form. Some are composed of a heterogeneous mixture of rocks, some of which are abraded "cobbles" derived from underlying rocks. Others are shattered or mildly brecciated and little rock movement is indicated. The pipes range from very permeable breccias having large open spaces to tightly packed breccias with fine rock powder filling the opening between the coarser fragments. In age they range from before the accumulation of the Grayback Mountain rhyolite tuff to after intrusion of quartz monzonite porphyry. In terms of geologic time, however, the period of breccia formation may not have been long.

ORIGIN

The origin of breccia pipes and dikes has long been a baffling geologic problem because no widely accepted explanation can be made. In the Bagdad area it appears that a definite relationship exists between pipe formation and igneous activity. True, there is no obvious connection of the southern pipes with the Grayback Mountain tuff, except for the assumption that volcanic activity that produced the rhyolite tuff might have formed these pipes before the deposition of the tuff. Evidence for a genetic relationship of the other pipes to the rhyolite, quartz monzonite, diorite porphyry, and quartz monzonite porphyry is shown by partial or complete brecciation of each of these rocks in different pipes, and also by unbrecciated intrusions. Furthermore, the evidence is conclusive in some pipes and in the northern breccia dike that some fragments have been transported upward. Hot juvenile gases derived from the associated magmas undoubtedly would provide the energy for this and for shattering and brecciation as well, but the process by which the gases operated to produce these changes is speculative. No evidence is present in the Bagdad area that volcanic pipes extended to the surface, but such a possibility exists.

The following statement by Burbank (1941, p. 177) for the origin of the pipes in the San Juan Mountains is as good an explanation as can be offered:

> The inferred history of pipe formation may be briefly summarized up to the point of complete development of the pipe, * * *. The passage of magmatic emanations up through favorably jointed and fissured rock may have caused certain chemical or volume changes along some vertical axis of greatest concentration, which impaired the strength of the rock and induced local crackling and crumbling. The zone of disintegration spread outward from the axis along generally curved surfaces * * *. As the breccia mass spread into the surrounding rock it tended to assume the form either of a ring zone, or a cylindrical core. When the breccia core became partly displaced with intrusive rock, * * * further external fracturing ensued as the result of upthrusting by the intrusive body.

When gas pressure was unusually great, gas explosions probably carried fragments upward, and abraded them during transport.

The possibility cannot be denied that subsidence may have occurred, particularly in the pipes that are largely shattered host rock, but neither can it be denied that local upward movement has taken place, and rock fragments have been rounded by abrasion. Again a mass of breccia might have been uplifted bodily by the upward thrust of an underlying plug or domelike intrusive mass, accounting for some pipes containing fragments derived from rock units below.

PHYSIOGRAPHY

The physiographic forms in the Bagdad area are controlled largely by the geologic formations; the mesas represent erosional remnants of lava flows, and the very extensive lava mesas to the north have been dissected only by the major streams. The mountainous areas are composed of the pre-Gila(?) rocks, largely pre-Cambrian metamorphic rocks and granite. The details of physiographic development are related in most part to the structure and character of the underlying rocks. The lava mesas reflect recent structural features such as warping and faulting. Excellent physiographic evidence is present of the postlava faulting along the Hillside and Bozarth faults. These scarps may be fault-line scarps, for if an appreciable cover of Gila(?) conglomerate was formerly present on top of the Sanders basalt, the erosion of this conglomerate from the dropped blocks may have exposed the present scarps. However, no adequate information is available as to the thickness of conglomerate deposited after the Sanders basalt and the suggestion of fault-line scarps is only a possibility. Considerable landsliding and block fall has taken place from these fault scarps, particularly along the Bozarth fault, resulting in the formation of local basins filled with alluvium.

Where a thick accumulation of conglomerate and interbedded lava flows took place, some cliff-bench topography has resulted, suggesting from a distance that the erosional scarps behind the lava benches may be fault scarps, but the character of the basalt lava of the Wilder formation in the benches, disproves this possibility. These features are illustrated on the north side of Centipede Mesa and at the southeast corner of Bozarth Mesa.

In the pre-Cambrian rocks, some variation in resistance to erosion is evident; and the granite, gabbro, and Bridle formation as a rule are less resistant, whereas the rhyolite and alaskite porphyry control the location of the ridges. Even in the Bridle formation, where lavas are more abundant, higher ridges are present than where interbedded tuffaceous sediments are thicker. In the granitic areas, the masses of aplite-pegmatite are more resistant to erosion, rising abruptly from the surrounding rocks. Some of the masses of muscovite granite in the northeast area of Lawler Peak granite are more resistant than the normal granite, rising sharply above the surrounding surface. The quartz monzonite, however, is very weak, cropping out in areas of lower relief.

In some of the private reports to the Bagdad Copper Corp. and its predecessors, statements have been made that a pre-Gila(?) peneplain existed (Thomas, 1934, p. 707) but the evidence is contrary to this belief. It is true that areas of rather low relief are present, particularly south of Sanders Mesa and south of Lawler Peak and one is buried beneath the Gila(?) conglomerate southeast of Centipede Mesa. The evidence is more conclusive, however, that the pre-Gila(?) surface had as great or greater relief than the present erosion surface, which is far from being a peneplain. Canyons were cut as deep or deeper than the present canyons, and were filled with Gila(?) conglomerate and interbedded lava flows and tuffaceous sediments.

The courses of the present major streams, Boulder, Copper, and Bridle Creeks, in part at least, were determined by the surface formed after the filling of the old canyons. Copper Creek to the west of Copper Creek Mesa may have started flowing along the edge of the old valley fill and the same control probably determined its course on the north side of Sanders Mesa. Two possibilities can be suggested for the separation of Copper Creek Mesa from Sanders Mesa: one, that the course of the stream was determined by the sedimentary cover on the lavas, so that the stream is superimposed in crossing the mesas; the other possibility is that a tributary of Copper Creek by headward erosion captured the headwaters of Butte Creek, and faulting of the mesa started this rapid headward erosion. Boulder Creek in its west course in the northern part of the area may have had its course determined by the southern margin of the lava flows and sediments along the older valley wall. The southern course between the Bozarth and Hillside faults may have been determined by the zone of faulting; a graben was formed and Boulder Creek cut down through the block west of the Bozarth fault as rapidly as faulting occurred. The western course of Boulder Creek could have been superimposed from the sedimentary cover on the Sanders basalt.

The tributaries to these major streams have steep gradients where they flow in deep canyons in their lower courses, but the gradients and the relief are lower in their headwaters. The same statement is true for the headwaters of Copper and Bridle Creeks; but rejuvenation of the upper courses will occur in future geologic time.

Terrace remnants and boxlike inner gorges, 40 to 50 feet deep, show that there has been recent rejuvenation along the major canyons except along the lower course of Boulder Creek, which has temporarily reached grade and is filled with alluvial material for a maximum width of 1,200 feet. Possibly graded condition has been reached here, because Boulder Creek is crossing an old canyon filled with soft sediments.

ORE DEPOSITS

HISTORY AND PRODUCTION

The name of John Lawler is closely associated with the early history of mining in the Bagdad area. Mr. Lawler started locating claims in 1880 and, either through location or purchase, acquired complete or part ownership of most of the favorable mineralized ground. He was one of the organizers of the Eureka Mining district, formed August 16, 1884; the Bagdad area is a part of this district.

The earliest mining operations were confined to the Hillside mine, located on March 11, 1887 by John Lawler and B. T. Riggs, who shipped oxidized gold-silver-lead ore on June 29, 1887 by pack train to Wilders Camp, 18 miles distant, and from there by wagons to Prescott, Ariz., where it was sold to the Arizona Sampling Works. The ore was then shipped to El Paso, Tex., for smelting. The first shipment, of 4,006 pounds, contained 3.15 ounces of gold per ton, 193.35 ounces of silver per ton, and 11.7 percent of lead and yielded a net return of $408.49 or $203.94 per ton.[2] By the end of October, 1887, 38 tons of ore had been shipped for a net profit of $4,214.53 or $110.90 per ton. A road was built to Camp Wood, where a sawmill was constructed to obtain mine timber. Beginning on November 26, 1887, the ore was hauled by wagon via Camp Wood to Garland, 84 miles from the mine. Garland was a shipping point on the Prescott and Arizona Central Railroad that formerly connected Prescott with Seligman, Ariz. This railroad, long since abandoned, connected with the Atlantic and Pacific Railroad at Seligman. Beginning November 15, 1888, the ore was shipped by way of Seligman to many smelters in the Western States.

The Atcheson, Topeka, and Santa Fe Railway Co., successors to the Atlantic and Pacific Railroad, constructed a branch line from Ash Fork to Phoenix, and, by 1896, a road was built from the Hillside mine to Hillside station on this branch line, a distance of only 34 miles. The first shipment of ore from the Hillside mine via Hillside station was made on March 26, 1896, and all subsequent shipments from all the mines in the area have been made via Hillside Station.

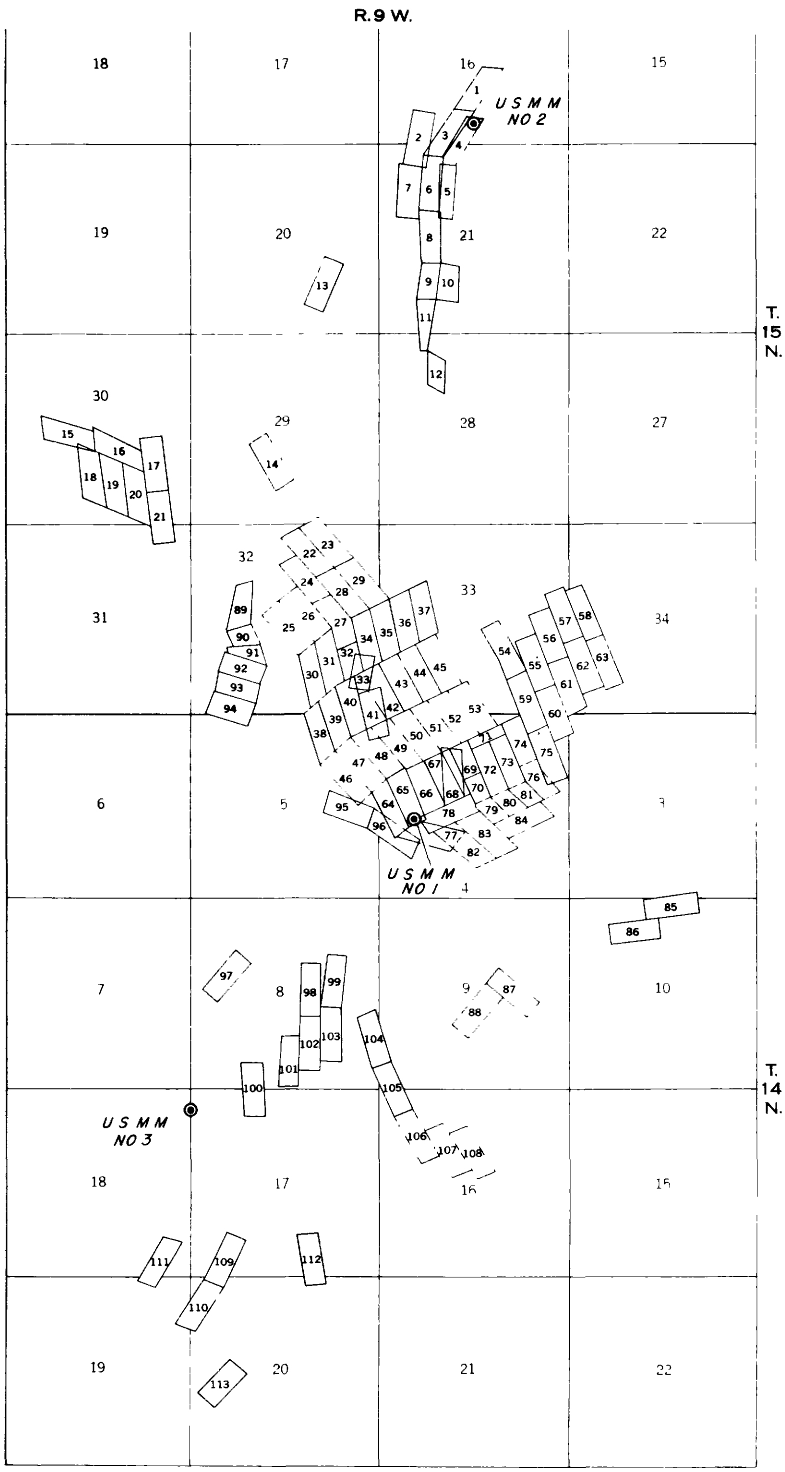
The Comstock claims (fig. 7) south of the Hillside mine, was located in 1892, and the adjacent Dexter claim was located in 1896. Oxidized gold and silver ore was mined from the two claims before 1901, and a small stamp mill was operated until sulfide ore was reached on lower levels.

Until 1917, the only metals mined in the Bagdad area were gold and silver and associated lead and copper. The Hillside mine had produced most of the ore, and the records are incomplete for other sources of ore, except for small shipments from the Cowboy mine, starting in 1911, and from the Stukey claims in 1916. During this period of gold mining the Old Camp Mining and Milling Co. in 1907 started an extensive exploration for gold in the area where small quartz veins crop out east of King Peak. The company drove 3 adits and patented 13 claims, but no ore was shipped, and title to the claims eventually passed to the State of Arizona, because of delinquent taxes.

The copper minerals on the Bagdad and adjacent claims were recognized as early as 1882, when the first claims were located, but little exploration for copper was done until 1906, when the E. M. Bray Trust Co. purchased 8 patented and 12 unpatented claims. This company and its successors carried on an exploration program that continued intermittently until 1929, when the first copper ore was mined. The first exploration, started in 1906, consisted of driving a number of adits and demonstrated that the copper deposit is of the disseminated type. In 1909 churn drilling was begun and was carried on intermittently until 192?.

During World War I, mining activity was largely limited to the Copper King mine, which became an

[2] For information on the early history of the Hillside mine, the writers are indebted to Homer R. Wood of Prescott, Ariz.



NO.	CLAIM	OWNERSHIP
1	HAPPY JACK	East Vulture Mining Co
2	CAMP	
3	SEVEN STARS	
4	CONTACT NO 2	
5	CONTACT NO 1	
6	HILLSIDE	
7	RESURGAM	M L Lynch and J. W. Lawler
8	1ST SOUTH EXTENSION HILLSIDE	M L Lynch and J W Lawler, Estate of J L Howells
9	2ND SOUTH EXTENSION HILLSIDE	
10	MUSCAL	
11	COMSTOCK	Comstock-Dexter Mines Inc
12	DEXTER	
13	GOODENOUGH	M L. Lynch, J W Lawler, Mrs E W Blake, and Mrs Elmer Wells
14	CUPRUM	M L Lynch and J. W Lawler
15	ORION	Bagdad Copper Corp
16	BISMARK NO 3	
17	BISMARK NO 1	
18	IRON KING NO 1	
19	IRON KING	
20	BISMARK NO 2	
21	HENRY	
22	CENTIPEDE	
23	TARANTULA	
24	NORTHERN	
25	EMPIRE	
26	DEPRESSION	
27	EUREKA	
28	SCORPION	
29	HUALAPAI	
30	NORTH STAR	
31	COPPER SULPHURETS	
32	ETA	
33	BLACK MESA	
34	IOTA	
35	YAVAPAI	
36	TOP KNOT	
37	OSKALOOSA	
38	ALUM CREEK CHIEF	
39	COPPER CLIFF	
40	COPPER SLOPE	
41	NATURAL POINT	
42	COPPER FILLING	
43	MALAPAI	
44	SUMMIT	
45	BEACON	
46	COPPER GLANCE	
47	MOUNTAIN DEPOSIT	
48	TRAPEZOID	
49	MINT	
50	MINT ANNEX	
51	RIM ROCK	
52	HILL TOP	
53	BRONSON	
54	SUNSET NO 5	
55	SUNSET	
56	SUNSET NO 1	
57	SUNSET NO 6	
58	SUNSET NO 8	
59	VENTURE	
60	SUNSET NO 3	
61	SUNSET NO 2	
62	SUNSET NO 7	
63	SUNSET NO 9	
64	SOUTH EXTENSION MOUNTAIN DEPOSIT	
65	HAWKEYE ANNEX	
66	HAWKEYE	
67	WEDGE	
68	LITTLE CHIEF	
69	FRACTION	
70	NORTH BAGDAD	
71	RATTLER	
72	BAGDAD ANNEX	
73	SPRING	
74	NIAGARA	
75	SUNSET NO. 4	
76	COPPER CREEK	
77	CONFIDENCE	
78	CROSS	
79	BAGDAD	
80	EAST BAGDAD	
81	SOUTH SPRING	
82	WEST BAGDAD ANNEX	
83	WEST BAGDAD	
84	SOUTH BAGDAD	
85	SUN	
86	MOON	
87	EMERALD	
88	RUBY	
89	NIAGARA NO 1	Vera Voge and the Coronado Development Corp
90	NIAGARA NO 2	
91	NIAGARA NO. 3	
92	NIAGARA NO. 4	
93	NIAGARA NO. 5	
94	NIAGARA NO. 6	
95	AMIGO	John Dougherty, Alice Bauder and Mrs Herman Voge
96	PALESTINE	
97	COPPER KING	M L Lynch and J W Lawler
98	CARBON	State of Arizona
99	GALENA NO 9	
100	LUCKEY STRIKE	
101	ALICE L	
102	CAMP BIRD	
103	AMERICAN FLAG	
104	ARIZONA BELLE	
105	EUREKA CHIEF	
106	LAST CHANCE	
107	COPER KING	
108	BLACK QUEEN	
109	OLD DICK	M L Lynch, J W. Lawler, Elmer Wells, and Minnie A. Wells
110	1ST SOUTH EXTENSION OLD DICK	M L Lynch and J W Lawler
111	YOUNG DICK	
112	MOUNTAIN SPRING	
113	COPER QUEEN	

0 — 2 Miles

FIGURE 7.—Map of patented claims, Bagdad area, Arizona.

important producer of zinc. The Copper King claim was located in 1881, but no zinc ore was shipped until 1917. At that time the Arizona Hillside Development Co. obtained an option on the mine and operated continuously until 1921. In 1925 the World Exploration Co. obtained control and shipped ore until 1927, when the decline in the price of zinc forced them to close the mine. Sphalerite was the chief ore mineral. After hand sorting at the mine, the ore was hauled, first by wagons and later by trucks, to Hillside. The haulage charge was $10 per ton. The shipped ore averaged 46.89 percent zinc, 5.7 ounces of silver per ton, 3.58 percent lead, and 1.68 percent copper. The total production to 1927 was valued at $719,907.

Copper mining at Bagdad began after the building of a pilot mill in 1928, resulting in the production of 277,501 pounds of copper in 1929. During 1930, an experimental block-caving stope was begun, and the success of the stoping method and satisfactory recovery from the mill encouraged mining on a larger scale after a period of inactivity that lasted from 1931 to 1934. In 1935 capacity of the pilot mill was expanded to 300 tons daily, and two stopes were mined, but the lack of water hampered further expansion of the mill.

The Hillside mine was purchased by the Hillside Mines, Inc., in 1934, and a concentrator with a capacity of 125 tons per day was built to mill the sulfide ores. In 1937 additional flotation cells in the mill provided for separation of the zinc from the lead. Operations continued to January 1942, when the mine was closed because of financial difficulties.

Small shipments of gold ore were made from the Kyeke mine in 1936 and 1937. In 1937 the Comstock-Dexter mine was reopened and a mill constructed, and in 1938 gold, silver, and lead were recovered.

Mining activity in the Bagdad area was expanded greatly during World War II. In anticipation of greater demand for copper, the Bagdad Copper Corp. obtained a $2,500,000 loan from the Reconstruction Finance Corporation and built a concentrator of 2,500 tons daily capacity and brought water from Burro Creek, 7 miles to the west, and prepared the mine for increased production, stimulated by premium prices. The road from Bagdad to Hillside on the Atcheson, Topeka and Santa Fe Railway was shortened and improved by Yavapai County and the Federal Government. Copper concentrates are now hauled by truck to Hillside and carried by railroad from Hillside, Ariz. to El Paso, Tex. for reduction. The new mill was started on March 1, 1943, and the production for the years 1943–51 inclusive has been 117,095,845 pounds of copper. Molybdenite was recovered in 1944–45, and again in the latter part of 1951 and in 1952. Mining methods were changed in 1945 to a combination of glory-hole and block-caving methods to increase production, and in 1947, open-pit mining was adopted. Daily output of the mill increased, and in 1950 a ball mill was added to the concentrator. In 1951 production averaged 3,500 tons daily.

Under the stimulation of premium prices for copper, lead, and zinc, other mines were active during World War II. Valerio Rossi operated the Copper King mine under lease and shipped oxidized copper, lead, and zinc ore and some sulfide ore from mine pillars. George Green and associates shipped 500 tons of oxidized copper ore from the Old Dick mine. Small shipments of lead ore were made from the Mountain Spring mine.

After World War II premium payments ceased, but mining activity has continued in the Bagdad area. In 1946–47 the Hillside Mining and Milling Co. dewatered and rehabilitated the Hillside mine and built a 100-ton flotation mill. Ore from the Hillside mine and custom ore were milled from 1948 to 1950. The Hillside mine was closed in 1951, but the flotation mill has continued operating as a custom mill, handling most of the zinc ore from the Old Dick and Copper King mines. In 1951 a 300-ton gravity concentrator was added to the mill to handle custom tungsten ore.

Sphalerite was discovered in the Old Dick mine during the exploration for oxidized copper ore during World War II. A winze, sunk much earlier in one of the adits, had found sulfide, though not of minable grade. The Goodwin Mining Co. purchased the Old Dick mine in 1947, and almost immediately discovered minable widths and grade of zinc-copper ore. The Old Dick mine became the leading producer of zinc in the Bagdad area. The Manhattan Consolidated Mines Development Co. purchased the mine in 1951.

The Goodwin Mining Co. purchased the Copper King mine in 1948 and shipped massive zinc sulfide ore to several custom mills. E. A. Scholz and J. H. Cazier purchased the mine in 1950.

In 1951 the Hillside Mining and Milling Co. opened the Tungstona mine located on Boulder Creek and began an active development program for mining the low-grade wolframite-bearing veins. Milling of this ore will be done at the Hillside mill.

A trenching and sampling program was started in 1952 to determine the extent and grade of the magnetite-ilmenite dikes in the gabbro in the western part of the Bagdad area.

Table 2, the record of past metal production in the Bagdad area shows clearly that gold, silver, and some lead, were the principal metals mined during the early mining history of the area, and that from 1887 to 1900 the Hillside mine provided most of these metals. From 1917 to 1927, the Copper King mine was an

TABLE 2.—*Metals produced in the Bagdad area, 1887–1951, in terms of recoverable metals*

[Production 1887–1900 of Hillside mine from records furnished by H. R. Wood, Prescott, Ariz. Production 1901–51, compiled by the U. S. Bureau of Mines]

Year	Gold		Silver		Copper		Lead		Zinc		Total value [1]
	Ounces	Value	Ounces	Value	Pounds	Value [1]	Pounds	Value [1]	Pounds	Value [1]	
1887	140		3, 419				5, 535				$4, 449
1888	950		17, 596				12, 058				27, 238
1889	1, 229		57, 221				7, 313				64, 078
1890	424		7, 840				4, 859				13, 418
1891	426		15, 633				2, 401				17, 423
1892	1, 940		41, 798				37, 456				67, 100
1893	707		14, 076				15, 104				23, 031
1894	216		4, 154				1, 799				5, 324
1895											
1896	850		12, 915				2, 668				21, 490
1897	261		4, 111				1, 873				6, 402
1898	159		4, 744				11, 917				5, 183
1899	409		7, 648				3, 923				10, 281
1900	105		1, 794								2, 502
1901	75	$1, 550	1, 525	$915							2, 465
1902	303	6, 264	4, 717	2, 500							8, 764
1903–5											
1906	271	5, 602	3, 726	2, 496							8, 098
1907–8											
1909	46	951	778	405			2, 091	$90			1, 446
1910	47	972	866	468	$11	$1	2, 349	103			1, 544
1911	189	3, 907	4, 270	2, 263	1, 044	131	11, 085	499			6, 800
1912	404	8, 351	9, 041	5, 560	94	16	17, 243	776			14, 703
1913											
1914	107	2, 212	2, 830	1, 565			4, 037	157			3, 934
1915–16											
1917	5	103	2, 568	2, 116	5, 350	1, 461	21, 400	1, 840	422, 402	$43, 085	48, 605
1918	3	62	1, 960	1, 960	7, 700	1, 902	16, 200	1, 150	357, 380	32, 522	37, 596
1919									1, 717, 000	125, 341	125, 341
1920							69, 790	5, 583	1, 457, 296	118, 041	123, 624
1921–24											
1925	19	393	1, 134	786	7, 594	1, 078	7, 450	649	184, 466	14, 019	16, 925
1926	22	455	28, 539	17, 808	126, 408	17, 697	313, 427	25, 074	3, 949, 154	296, 187	356, 221
1927	35	723	2, 105	1, 193	7, 761	1, 017	35, 443	2, 233	141, 232	9, 039	14, 205
1928											
1929	4	83	485	259	277, 501	48, 840					49, 182
1930	1	21	741	285	245, 203	31, 876					32, 182
1931	17	351	536	155	150	14	3, 642	135			655
1932	10	207	218	61	170	11	2, 367	71			350
1933	1	26									26
1934	3, 660	127, 917	90, 882	58, 751	20, 037	1, 603	8, 755	324			188, 595
1935	7, 259	243, 065	183, 280	131, 732	220, 880	18, 333					404, 130
1936	8, 937	312, 795	201, 821	156, 311	945, 005	86, 940	525, 800	24, 187			580, 233
1937	7, 119	249, 165	147, 413	114, 024	1, 544, 328	186, 864	1, 178, 816	69, 550	18, 877	1, 227	620, 830
1938	7, 709	269, 815	183, 139	118, 393	764, 823	74, 953	1, 303, 826	59, 976	81, 188	3, 897	527, 034
1939	3, 811	133, 385	93, 374	63, 382	326, 977	34, 006	797, 233	37, 470	673, 700	35, 032	303, 275
1940	2, 031	71, 085	53, 036	37, 714	1, 514, 600	171, 150	545, 300	27, 265	455, 877	28, 720	335, 934
1941	5, 274	184, 590	68, 773	48, 905	2, 287, 331	269, 905	1, 263, 000	71, 991	1, 252, 000	93, 900	669, 291
1942	715	25, 025	20, 389	14, 499	1, 107, 536	132, 904	128, 600	8, 359	127, 700	10, 535	191, 322
1943	31	1, 085	14, 771	10, 504	7, 026, 145	843, 137	24, 759	1, 609	48, 000	3, 960	860, 295
1944 [2]	83	2, 905	25, 418	18, 075	9, 712, 400	1, 165, 488	93, 800	6, 097	478, 500	38, 651	1, 231, 216
1945 [3]	363	12, 705	31, 945	22, 716	8, 101, 864	971, 880	142, 516	9, 264	1, 021, 925	84, 309	1, 100, 874
1946	139	4, 865	29, 699	23, 996	11, 848, 590	1, 919, 471	103, 800	11, 314	501, 200	61, 146	2, 020, 792
1947	3	105	30, 703	27, 787	12, 941, 971	2, 717, 814	27, 179	3, 913	497, 680	60, 220	2, 809, 839
1948	233	8, 200	53, 029	47, 992	14, 452, 534	3, 136, 199	247, 445	44, 292	4, 642, 800	617, 492	3, 854, 175
1949	1, 151	40, 285	71, 983	65, 145	15, 782, 558	3, 109, 164	348, 335	55, 036	4, 500, 456	558, 057	3, 827, 687
1950	1, 758	61, 530	93, 562	84, 674	21, 315, 385	4, 433, 600	418, 543	56, 505	2, 917, 915	414, 344	5, 050, 653
1951 [4]	136	4, 760	67, 337	60, 939	18, 142, 517	4, 390, 489	119, 725	20, 712	4, 999, 820	909, 967	5, 386, 867
Total:											
1901–51	51, 971	1, 796, 515	1, 526, 593	1, 146, 334	128, 734, 467	23, 767, 944	7, 783, 956	546, 224	30, 436, 568	3, 559, 691	30, 816, 708
1887–1951	59, 787		1, 719, 542				7, 890, 862				31, 084, 527

[1] Ceiling prices used during periods of premium payments.
[2] 73,157 pounds molybdenum.
[3] 12,669 pounds molybdenum.
[4] 149,380 pounds molybdenum, value $71.620.

important producer of silver, copper, lead, and zinc, and made the first shipments of recoverable zinc from the area. In 1929 copper and some silver was produced at Bagdad, but continuous mining activity did not begin until 1935. The Hillside mine resumed operations in 1934 and was an important producer of gold, silver, and lead until 1942; zinc has been recovered since 1937. The main production since 1942 has been from Bagdad, Hillside, Copper King, and Old Dick mines, and silver, copper, lead, and zinc have been the important metals.

MINERALS OF THE BAGDAD AREA

Only the minerals genetically related to the formation of the ore deposits will be described, as the common rock-forming minerals are of no economic importance and have no bearing on the origin of the ore deposits. Some of the pegmatitic minerals are of mineralogic interest, and their occurrence is mentioned in the description of the pegmatites (p. 20–21). The ore and associated minerals are grouped according to their origin; those formed by ascending ore-forming solutions (hypogene minerals) and those formed by the action of descending solutions (supergene minerals). The latter group includes sulfides as well as oxides, carbonates, and sulfates. Some of the so-called ore minerals, such as pyrite, have no economic importance, but because they are genetically related to the ore minerals, they will be described under that heading.

HYPOGENE MINERALS

ORE MINERALS

Pyrite, FeS_2.—This is the most abundant of the hypogene sulfide minerals in the Bagdad area. It is present in veinlets and as disseminated grains in the fractured quartz monzonite around the Bagdad mine, occurring locally within the chalcocite zone and also below it. On the outer margins of the copper mineralized area, pyrite is the chief sulfide mineral in the fractured rock and is particularly common in fractures along Alum Gulch. Pyrite is present in all the sulfide-bearing mines and prospects below the oxidized zone and occurs in veins, massive-sulfide replacement deposits, and breccia pipes. In these breccia pipes near the head of Alum Gulch the pyrite occurs in cubes as much as an inch in dimension.

Chalcopyrite, $CuFeS_2$.—This primary sulfide of copper and iron is found in nearly all the significant mineralized areas; it was not found in the Kyeke mine nor has it been reported from the Comstock-Dexter mine. It is the chief primary copper mineral in the Bagdad area. In the Bagdad mine, it occurs as small grains, either in veinlets or disseminated and always associated with pyrite. In the Black Mesa pipe it occurs as fairly large crystals as much as one-half inch across. In the veins and replacement deposits it usually occurs in small crystals, although in the Old Dick mine layers of chalcopyrite are associated with the sphalerite.

Molybdenite, MoS_2.—The brilliant gray flaky sulfide of molybdenum is common in the Bagdad mine, occurring in quartz-pyrite veins that are later than the pyrite-chalcopyrite veins. The crystals range in size from minute flakes to large grains one-quarter of an inch in diameter. Molybenite is found in the Black Mesa pipe, occurring chiefly in veinlets along the margins of the quartz that is interstitial to the breccia fragments. This mineral was noted also in the Mammoth prospect.

Galena, PbS.—The sulfide of lead is the chief ore mineral found in the Mountain Spring mine and several of the small veins west of Lawler Peak. It is an important ore mineral in the Hillside, Old Dick, and Comstock-Dexter mines. Small quantities of galena appear in many of the smaller veins, such as the Stukey and the Cowboy veins. Coarse crystals of galena are rare in some of the quartz veins in the Bagdad mine. Much of the silver in other deposits appears to be associated with the galena.

Sphalerite, ZnS.—This mineral is the chief primary zinc ore mineral in the Copper King and Old Dick mines, occurring as granular massive replacement ore. It is a common constituent of the Hillside vein and occurs in small quantities in many of the smaller veins. A few occurrences were noted in the Bagdad mine in a quartz-pyrite vein associated with rare galena.

Tetrahedrite, $(Cu,Fe)_{12}Sb_4S_{13}$.—Gray copper ore is found in the Hillside mine as small gray crystals attached to vuggy quartz. It may be the arsenical variety, tennantite. A sample yielded a silver bead on assaying, indicating that it is argentiferous, possibly the variety freibergite. Tetrahedrite was found in coarse crystals associated with galena in one of the quartz veins in the Bagdad mine; the identification as tetrahedrite was confirmed by Charles Milton of the Geological Survey by chemical and X-ray methods.

Arsenopyrite, FeAsS.—In the Kyeke mine, this mineral is the chief primary sulfide ore mineral, forming irregular bunches in quartz. Small aggregates are present in the Hillside vein.

Arsenopyrite is a common constituent in some of the massive-sulfide ore from the Old Dick mine, occurring as euhedral crystals as much as a quarter of an inch long; locally it comprises as much as 30 percent of the sulfide mass. Because an X-ray powder pattern indicated the presence of some cobalt, some hand-picked crystals were analyzed by Norman Davidson of the Geological Survey, who found a cobalt content of 1.21 percent, which is too low for the variety danaite that contains 3–9 percent Co. Four of these cobaltian arsenopyrite crystals were examined in polished section by Charles Milton of the Survey who reports:

> It was immediately apparent that the crystals carried as small inclusions crystals of pyrite, readily visible with a hand lens. . . . The arsenic mineral itself is complex, the crystals showing definite zoning of two phases. In addition, there are oriented intergrowths, which may possibly be twinning, but more likely are intergrowths of two minerals of not greatly differing composition.

Spectrographic determinations of the cobalt content of other arsenopyrite samples were made by K. J. Murata of the Geological Survey, who reported no cobalt in arsenopyrite from the Hillside mine; 0.03 percent cobalt in arsenopyrite from the Kyeke mine; and 0.3 and 0.6 percent cobalt respectively in two crystals from the Old Dick mine. The arsenopyrite from the Old Dick therefore has a variable cobalt content.

Gold, Au.—This mineral is of economic importance in the Hillside and Comstock Dexter mines, occuring both in the primary and the oxidized parts ot the vein. It was the chief metal sought in the Stukey, Cowboy, and Kyeke mines. Traces of gold are found in ores from the Bagdad, Copper King, and Mountain Spring mines. No free gold was observed, but the mill tests on ore from the Hillside mine indicated that the gold was chiefly associated with the pyrite and arsenopyrite in the primary ore.

Argentite, Ag_2S.—Small delicate crystals of argentite are found only in the Hillside vein, where they are attached to crystals of vuggy quartz. Although found in association with tetrahedrite and other primary sulfide minerals, there is a possibility that the argentite is supergene in origin.

Magnetite, Fe_3O_4.—Magnetic iron ore is found with sulfide minerals in the Copper King mine; it is subordinate in amount to hematite and appears along the margins and ends of the massive-sulfide lenses. It was probably deposited during the early stages of mineralization. Magnetite in small crystals is associated with pyrite and chalcopyrite in the Bagdad mine. Magnetite also occurs associated with ilmenite in lenses or dikes in the gabbro.

Ilmenite, $FeTiO_3$.—This mineral occurs as granular crystals, subordinate in amount to magnetite in lenses or dikes in the gabbro.

Hematite, Fe_2O_3.—The platy variety, specularite, forms small masses at the Copper King mine, associated with a little magnetite. Under the microscope minute inclusions of specular hematite are visible in the magnetite from lenses in the gabbro. Specular hematite appears in narrow veinlets cutting the more southerly breccia pipes.

Wolframite, $(Fe,Mn)WO_4$.—The tungstate of iron and manganese appears as small crystals in quartz veins at several localities in the northeastern area of Lawler Peak granite. Along Boulder Creek near the eastern margin of the area, the crystals appear as small brown prisms ranging from one-eighth to one-fourth of an inch in length associated with beryl and quartz. A qualitative spectroscopic analysis made by the John Herman Laboratory, Los Angeles, indicates a low manganese content, indicating that the wolframite is near the ferberite end of the ferberite–hubnerite series. It is reported that wolframite also occurs in the Black Mesa breccia pipe.

Scheelite, $CaWO_4$.—The tungstate of calcium is rare in the Bagdad area. A few crystals were found on the dump of the Bagdad mine by use of an ultraviolet lamp; this determination was checked under the microscope. It is reported that scheelite occurs in the quartz-epidote facies of the Bridle formation. Thin coatings are present on surface exposures associated with wolframite; it is reported that scheelite is present in the underground workings of the Tungstona mine.

GANGUE MINERALS

Quartz SiO_2.—This is the most common gangue mineral of the hypogene minerals, occurring in all the vein deposits and breccia pipes that show sulfide mineralization. Quartz is common in the Bagdad mine as the gangue of numerous small veins and as the filling in the minute fractures. In the breccia pipes with large openings between fragments, the quartz is vuggy, and forms numerous clear prisms that range from one-quarter to one-half inch in diameter and an inch in length. Although no prisms were found to be clear enough for optical purposes, many beautiful mineral specimens can be collected from the breccia pipe near the mouth of Niagara Creek.

Muscovite, $KAl_2(AlSi_3)O_{10}(OH)_2$.—The fine-grained variety of this mineral, sericite, is found in local areas around the Bagdad mine, associated with quartz. Some of the flakes are almost coarse enough to warrant the term "muscovite." Sericite was observed in many thin sections of the altered quartz monzonite and occurs as nests and veinlets in the plagioclase or associated with quartz and orthoclase in veinlets. Sericite is also a common hypogene mineral in the country rock adjacent to the veins and massive sulfide lenses.

Orthoclase, $KAlSi_3O_8$.—Clear orthoclase is a common hypogene mineral associated with quartz in the altered quartz monzonite and in veins, in the Bagdad mine.

Albite, $NaAlSi_3O_8$.—The soda feldspar is common in the altered quartz monzonite around the Bagdad mine, where it replaces the original calcic oligoclase or andesine. Some of albitized plagioclase retains a little lime and is sodic oligoclase in composition. Sericite is a common associate.

Biotite, $K(Mg,Fe)_3(AlSi_3)O_{10}(OH)_2$.—Leafy black mica is common in the altered quartz monzonite around the Bagdad mine, formed by the recrystallization of the original book biotite of igneous origin, and from hornblende.

Chlorite, $H_8Mg_5Al_2Si_3O_{18}$.—Green chlorite occurs locally in the altered quartz monzonite around the Bagdad mine, replacing biotite concurrent with the separation of magnetite clusters.

Rutile, TiO_2.—Microscopic crystals of rutile are present in the altered quartz monzonite in the Bagdad mine as needles in the biotite and chloritized biotite and as stubby crystals and granular aggregates attached to the biotite or mixed with the quartz and orthoclase.

Barite, $BaSO_4$.—Small platy crystals of bluish-white barite were picked out of muck piles by miners in the Bagdad mine on several occasions; the specimens show that the barite occurs in small pockets in the fractured quartz monzonite. Some cream-colored barite was found in veins carrying galena and sphalerite, indicating it was late in the sequence of mineralization. Barite is reported in the Comstock-Dexter mine by Hoagland (1937).

Manganosiderite, $(Fe,Mn)CO_3$.—Pale pinkish-gray carbonate of iron and manganese appears locally in the Hillside vein, usually in close association with tetrahedrite. According to Charles Milton of the Geological

Survey, microchemical tests of this mineral show much iron and manganese and no zinc.

SUPERGENE MINERALS

ORE MINERALS

Chalcocite, Cu_2S.—The copper mineral of most economic importance in the Bagdad mine is chalcocite, formed by supergene enrichment replacing chalcopyrite and pyrite. In the initial stages, only chalcopyrite is replaced; in many specimens there is a rim of chalcocite on the chalcopyrite, whereas the adjacent pyrite is unreplaced. Most of the chalcocite is steel gray, but in some of the wider quartz-pyrite veins it is commonly of the sooty variety where it has replaced the pyrite. Small quantities of chalcocite were observed at the Mammoth prospect and Copper King and Hillside mines. Chalcocite coatings on chalcopyrite are common in the adit level of the Black Mesa breccia pipe and chalcocite coatings on pyrite were observed in the other mineralized breccia pipes.

Covellite, CuS.—The other supergene sulfide of copper, covellite, is not a common mineral in the Bagdad area, and it was recognized in the Bagdad mine only by microscopic study of the ore minerals; covellite occurs chiefly as the first replacement product of the chalcopyrite. In some of the sphalerite-bearing veins, such as the Hillside vein, covellite coatings on sphalerite were found at the base of the oxidized zone.

Copper, Cu.—Native copper is fairly common in the oxidized zone of the Bagdad mine, occurring as small irregular masses and wires associated with cuprite. Along some of the fractured veins in the chalcocite zone, local oxidation of the chalcocite has occurred with some cuprite and native copper appearing mixed with chalcocite. Some small stringers of native copper were found at the surface in some of the small prospects.

Cuprite, Cu_2O.—The red oxide of copper is readily found in the oxidized zone of the Bagdad mine, particularly where narrow veins of chalcocite have been oxidized. It also occurs in the chalcocite zone where faults have allowed deep penetration of meteoric waters. Locally, the brilliant red hairlike variety, chalcotrichite, is present. Cuprite is also found at the Old Dick and Copper King mines and the Mammoth prospect.

Malachite, $CuCO_3{\cdot}Cu(OH)_2$.—The green carbonate of copper is fairly common in the oxidized zone of the Bagdad mine and is conspicuous on Copper Creek along some of the small fault zones in the quartz monzonite northwest of the mine. It is a common constituent of the oxidized copper ore shipped from the Old Dick and Copper King mines. Malachite can be found in the oxidized portion of all the copper-bearing veins, such as the Hillside, Mountain Springs, Stukey, and Cowboy deposits. Locally, along Copper Creek, malachite and chrysocolla are conspicuous cementing materials of the terrace gravels.

Azurite, $2CuCO_3{\cdot}Cu(OH)_2$.—The blue carbonate of copper is usually found in minor quantities associated with the malachite. It is most abundant along Copper Creek, northwest of the Bagdad mine.

Chrysocolla, $CuSiO_3{\cdot}2H_2O$.—The silicate of copper is the most common mineral of the bluish to green coatings found on the rocks in the oxidized zone of the Bagdad mine. In many places it occurs in bands alternating with lesser amounts of malachite. The chrysocolla ranges in color, from bluish white, greenish blue to blue. Locally along the Hawkeye fault, chrysocolla occurs in many veins, each an inch or more in width. It also occurs with malachite in the oxidized zone of all the copper-bearing veins and sulfide-replacement deposits.

Chalcanthite $CuSO_4{\cdot}5H_2O$.—The water-soluble sulfate of copper is found in nearly all the dry underground workings where other copper minerals are present. Along the walls it forms crusts that are not uniform in thickness, but those along the adit in the Black Mesa breccia pipe are most conspicuous, locally attaining a thickness of 2 and 3 inches. Chalcanthite is also found on the lower level of the Bagdad mine near the main ore body.

Antlerite $CuSO_4{\cdot}2Cu(OH)_2$.—This pale-greenish, minutely fibrous copper mineral is rare in the Bagdad area, occurring only in the walls of the adit in the Black Mesa breccia pipe, where it is associated with chalcanthite. The lower index of refraction was determined as slightly more than 1.72 and most of the fibers show a negative elongation because of the (010) cleavage, but a few have a positive elongation indicating Y is parallel to the fibers. The range in pleochroism is from almost colorless in X to pale green in Y and Z.

Copper pitch ore (melanochalcite), variable mixture of copper, manganese, and iron hydrous oxides mixed with colloidal silica.—Copper pitch ore occurs along the more pronounced fractures in the quartz monzonite along Copper Creek, northwest of the Bagdad mine, occurring as black scaly to pitchy coatings along the fractures. Charles Milton and Joseph M. Axelrod of the Geological Survey report:

> the Bagdad mine material consists of small homogeneous black conchoidally-fracturing coatings, less than a millimeter thick, which do not have sharp boundaries from pale green material, similar except for color. Both green and black substances gave extremely poor X-ray patterns, indicative of non-crystallinity. The black material is brown and translucent in powder, and apparently strongly anisotropic with a banded gel-like structure. The anisotrophy may be a strain phenomenon. Solution of black substance in dilute nitric acid was slow with slight effervescence; adding H_2O_2 accelerated solution greatly. A pale green siliceous residue of the same size and shape of the original grain was left. The solution gave a strong test for copper, a

weaker test for manganese and little or no reaction for iron or zinc. Much water is present.

Guild (1929) has described other Arizona occurrences of this mineral, known also as melanochalcite.

Hemimorphite (*calamine*), $H_2Zn_2SiO_5$.—The silicate of zinc occurs as beautiful, clear, prismatic crystals and also in botryoidal crusts in the oxidized zone of the Copper King mine, where it is a common constituent of the oxidized zinc ore. It was also found in the oxidized zone of the Hillside and Mountain Spring mines.

Smithsonite, $ZnCO_3$.—The carbonate of zinc is a common constituent of the oxidized zinc ore at the Copper King mine, rarely occurring in crystalline form, but is usually earthy (dry bone). It was also found in the oxidized zone of the Hillside mine.

Goslarite, $ZnSO_4 \cdot 7H_2O$.—This efflorescent deposit is common in the upper levels of the Hillside mine, occurring as silky, white fibers perpendicular to the drift walls; in places the fibers are 2 inches long. It is also found in the upper workings of the Copper King mine. During exceptionally dry summers, the dump of the Copper King mine becomes heavily coated with goslarite that disappears during the winter rains. When the coating of goslarite is thick, as it was in the summer of 1944, the snow-white color makes the dump easily visible from a distance.

Conichalcite, $CuCa(OH)AsO_4$.—This mineral was found only at the Copper King mine, where it forms a green, radiating fibrous coating on the oxidized ore. It is easily distinguished from malachite under the microscope, owing to its low birefringence and parallel extinction. Charles Milton made the following report:

> Optical examination indicates that the mineral could well be conichalcite, or rather higginsite, shown by Strunz (Z. Krist. 101, 496, 1939) to be the same substance. . . . By direct comparison of the X-ray pattern of the Copper King mineral with that of known conichalcite from Tintic, Utah (which in turn has been shown by Strunz to be the same chemically and crystallographically as higginsite), its identity as conichalcite is established. It bears the same relation to higginsite as chalcedony does to quartz.

Because this mineral occurs in the Copper King as minute radiating fibers, it has been named conichalcite in this report.

Silver, *Ag*.—Native silver was observed only in the oxidized zone of the Hillside mine, where it occurs as wires or as arborescent bunches. Assays that show appreciable content of silver in the oxidized ores of the Comstock-Dexter, Copper King, Old Dick, Stukey, Cowboy, and Kyeke mines probably indicate that native silver may be present but none was identified in this study.

Cerargyrite ($AgCl$).—Horn silver or cerargyrite is found in the oxidized zone of the Hillside vein and along some adjacent postmineral faults. It probably contains some of the silver in the oxidized ores of the mines mentioned in the preceding paragraph.

Cerussite, $PbCO_3$.—The carbonate of lead was found in the oxidized parts of all the mines and prospects containing primary galena. It occurred as gray to white crusts along fractures and as scattered crystal aggregates.

Anglesite, $PbSO_4$.—Lead sulfate was found associated with cerussite, usually as coatings around galena; this suggests that it was the first lead mineral to form under supergene processes.

Schroeckingerite, $Ca_3Na(UO_2(CO_3)_3SO_4F \cdot 10H_2O$.—This uranium mineral occurs in the Hillside mine on the 300-foot level north of the shaft. It is associated with other secondary uranium minerals, and gypsum coating the drift walls indicates a rather late accumulation of these minerals. The schroeckingerite occurs as scattered green rosettes associated with sulfur-yellow bayleyite; both minerals adhere to the mica schist of the drift walls.

Bayleyite, $Mg_2UO_2(CO_3)_3 \cdot 18H_2O$.—Bayleyite, another of the uranium minerals found in the Hillside mine, forms sharp, well-faceted sulfur-yellow crystals associated with schroeckingerite and coating gypsum. Bayleyite fluoresces weakly but the color is indeterminate.

Swartzite, $MgCaUO_2(CO_3)_3 \cdot 12H_2O$.—Swartzite is another secondary uranium mineral found in the Hillside mine. Swartzite occurs in green prismatic crystals intergrown with other uranium minerals and gypsum, The swartzite fluoresces bright yellowish green.

Andersonite, $Na_2CaUO_2(CO_3)_3 \cdot 6H_2O$.—Andersonite resembles swartzite superficially; andersonite forms bright yellow-green pseudo-cubic crystals that fluoresce bright whitish green. It is rarest of the uranium minerals found in the Hillside mine. A complete description of this mineral and the other secondary uranium minerals is given by Axelrod and others (1951).

Pharmacosiderite, $3FeO_3.2As_2O_5 \cdot 3(H,K)_2O \cdot 5H_2O$.—Bright emerald-green crystals that are probably pharmacosiderite were found at one place on the upper levels of the Hillside mine in the oxidized zone. Under the microscope the crystals are partly isotropic. The index of refraction is 1.655 ± 0.005, and there is some anomalous birefringence. These optical properties indicate that the crystals are pharmacosiderite.

Wulfenite, $PbMoO_4$.—Thin orange-yellow plates of wulfenite were found in the oxidized zone of the Mountain Spring deposit and at an outcrop of a small vein west of Bevering Gulch.

Pyromorphite $(Pb,Cl)Pb_4(PO_4)_3$.—Pale-yellow tufts of minute radiating prisms of pyromorphite are associated with wulfenite west of Bevering Gulch. The determination of this mineral was verified by an X-ray study made by Charles Milton of the Survey, who reported that spectrographic analysis revealed calcium and arsenic.

Ferrimolybdite, $Fe_2O_3 \cdot 3MoO_3 \cdot 8H_2O$.—Ferrimolybdite, sometimes known as molybdite, is very rare in the Bagdad area and was only found as radiating canary-yellow fibers at the outcrop of a small quartz vein in the gabbro near the southern tip of the large mass of aplite-pegmatite.

Jarosite, $K_2Fe_6(OH)_{12}(SO_4)_4$.—This product of the oxidation of pyrite is fairly common, particularly in the oxidized part of the primary-sulfide zone at the Bagdad mine. It is easily recognized because of the yellow powdery appearance and greasy feel when rubbed between the fingers. One of the stronger quartz veins in the Bagdad mine, exposed in the caved area, contained crystal aggregates of dense orange jarosite that are pseudomorphic after the original crystal forms of the pyrite.

Limonite (hydrated iron oxide).—Limonite is used as a field term for the ferric oxide that contains varying amounts of water; it commonly is yellow to brown and yields a yellow streak. Much of the powdery aggregate of this mineral probably includes jarosite. Limonite is found in the oxidized parts of all the pyrite-bearing veins and replacement deposits and the oxidized part of the primary-sulfide zone at the Bagdad mine. Some of the pyrite cubes in the breccia pipes are pseudomorphs of dark-brown limonite. Cellular to fluffy limonite, in places reddish, occurs in the oxidized zone of the Copper King mine, usually adjacent to or above the massive-sulfide lenses.

Over the chalcocite zone of the Bagdad mine, the limonite is maroon and yields a yellowish-orange streak; this variety of limonite develops from the oxidation of chalcocite and is significant, as it indicates the former presence of chalcocite. Microchemical tests, made by Lyman C. Huff of the Geological Survey, revealed about 1 percent copper in this maroon variety of limonite.

GANGUE MINERALS

Chalcedony, SiO_2.—The cryptocrystalline variety of quartz, chalcedony, is found in small quantities in the oxidized part of the Bagdad deposit as thin veinlets with or without chrysocolla.

Gypsum, $CaSO_4 \cdot 2H_2O$.—The hydrated sulfate of calcium occurs chiefly as an efflorescent deposit along the walls of the Hillside and Bagdad mines. In the older workings of the Bagdad mine efflorescent gypsum is an inch or more thick. At the Copper King mine the colorless transparent variety, selenite, is found in crystals as much as 2 inches long embedded in the oxidized ore.

Francolite, $10CaO \cdot 3P_2O_5 \cdot CO_2 \cdot CaF_2 \cdot H_2O$.—This member of the apatite group occurs at the surface over the Bagdad mine as minute, cream-colored hexagonal plates lining some of the fractures in the quartz monzonite. Some scattered crystals also appear in the limonite boxwork as replacements after the sulfides, proving the supergene origin of the francolite. The index of refraction is almost 1.630. J. M. Axelrod states that it has a high fluorine content and should therefore be called francolite rather than dahllite.

Hisingerite (hydrated iron magnesium silicate).—In the upper levels of the Hillside mine there are local brownish-black deposits of dripstone that coat the walls and form pendants from the back of the drifts. The dripstone breaks with a conchoidal fracture and has a greasy lustre. It is isotropic and has an index of refraction of $1.595 \pm .005$. These properties suggest that it is hisingerite of variable composition.

Clay (hydrous silicate of aluminum and magnesia).—Aggregates and films of greenish to yellow-brown clay occur along fractures and faults above the primary sulfide zone in the Bagdad mine. Differential thermal analyses of three samples of the clay were made by George Faust of the U. S. Geological Survey, who reported that the clay consists of a mixture of several minerals, but peaks for montmorillonite (used in a group sense) and kaolinite were present in all three records. J. M. Axelrod made X-ray-powder photographs of the same samples and reported that the clay minerals were kaolinite and a member of the saponite group. Because at present it is not possible to differentiate between members of the montmorillonite-saponite group by either method, all that can be stated is that one of the clay minerals belongs to this broad group, and the other is kaolinite.

CLASSIFICATION OF ORE DEPOSITS

The ore deposits in the Bagdad area can be classified in several ways. Hypogene mineralization, that is, deposition from ascending thermal solutions, formed the primary deposits, a few of which are of minable grade, such as the massivesphalerite of the Copper King and Old Dick mines and the gold-silver-lead-zinc Hillside vein. Hypogene deposits are frequently classified according to temperature, such as the hypothermal or high temperature deposits; the wolframite-bearing veins are of this type. The intermediate temperature class, the mesothermal, apparently is applicable to the rest of the hypogene deposits, although there is some evidence that much of the hypogene mineralization in the Bagdad mine occurred at higher temperatures, hypothermal or "hotter" mesothermal. Much of the ore in the Bagdad area has been affected by supergene action, that is, descending solutions, and this supergene enrichment is of major importance in the Bagdad mine, because it has increased the grade of copper sufficiently to form ore. In addition oxidation of hypogene and supergene sulfides has been an important process; some of the gold and silver ores came from the oxidized parts of veins and oxidized copper was the first ore produced from the Old Dick mine.

For the purpose of this report it appears more desirable to classify and describe the different ore deposits on the basis of form rather than origin, particularly because a combination of hypogene and supergene mineralization has been necessary to form ore, in some of the deposits. The largest production at the present time is from the disseminated-copper deposit in the quartz monzonite, where there has been appreciable supergene enrichment in chalcocite to form ore, and this type of mineralization is classified as a disseminated copper deposit enriched with chalcocite. Copper deposits are present in some of the breccia pipes in which supergene enrichment was an important process, and these will be classified as mineralized breccia-pipes. Two deposits, those of the Copper King and Old Dick mines, are massive-sulfide replacements of schist that have undergone appreciable supergene mineralization yielding ore, and they will be described under the heading Massive-sulfide-replacement deposits. Fissure veins are commercially important, whether or not enriched by supergene mineralization, and they will be described under the heading Gold-silver-lead-copper veins. The tungsten-beryllium vein deposit contains different minerals than the other vein deposits, therefore this deposit will be described separately.

DISSEMINATED COPPER DEPOSIT ENRICHED WITH CHALCOCITE

Most of the disseminated copper occurs in the quartz monzonite stock at Bagdad, so that a description of this type of deposit is essentially an account of the Bagdad mine. In detail, the hypogene sulfides chalcopyrite and pyrite, replaced locally by supergene chalcocite, occur in minute veinlets and some sulfide grains are disseminated between the veinlets, but from a broader viewpoint the copper minerals are "disseminated" rather than concentrated in larger veins. Some narrow quartz-pyrite-chalcopyrite veins are present, but the bulk of the copper occurs in the fractured quartz monzonite. Actually most of the so-called porphyry, or disseminated copper, ore is concentrated in fractures rather than truly disseminated in the host rock. The chalcocite enrichment in large part is related to the pre-Gila(?) erosion surface, and the highest grade of ore is found in a typical "blanket" beneath a leached zone and above the primary-sulfide zone, or protore. Some chalcocite enrichment in rock along Copper Creek northwest of the Bagdad mine appears to be related to the present erosion surface.

HYPOGENE ALTERATION

BIOTITE-ALBITE-QUARTZ-ORTHOCLASE FACIES

Much of the quartz monzonite in the central stock in and near the Bagdad mine appears unaltered and has little or no conspicuous chlorite and sericite to suggest the common type of hypogene-altered rock. However, petrographic studies reveal that the texture of sulfide-bearing quartz monzonite is granular, plagioclase is extremely sodic, the amount of orthoclase is equal to or in excess of plagioclase, biotite is leafy and pale, and hornblende is rare or is absent.

In the unaltered quartz monzonite, biotite occurs in book-habit; that is, the ratio of length along the *c* crystallographic axis to length along the cleavage approaches or even exceeds unity (fig. 8*A*). The index of refraction β in the book biotite ranges from 1.635 to 1.645.

The biotite in the altered facies is paler, is without strong pleochroism, and occurs in leaf habit; that is, the ratio of the length along the *c* axis to the length along the cleavage is much less than unity (fig. 8*B*). The index of refraction of β is lower than in the book biotite (table 3), ranging from 1.605 to 1.625. The chemical analysis of the altered rock containing leafy biotite (sample *B*, table 3) indicates that this mineral contains more MgO and less FeO than the book biotite in the unaltered rock. The only iron-bearing minerals in the altered rock are pyrite, chalcopyrite, biotite, and magnetite; and the only magnesia-bearing mineral is the biotite. If allowance is made for the iron necessary to combine with sulfur to form pyrite and chalcopyrite, the molecular ratio of remaining FeO to MgO is about 1 to 5.

Crystals of biotite were separated from three samples of quartz monzonite from the Bagdad mine by M. L. Lindberg of the Geological Survey, and the content of iron and water was determined. Table 3 shows the results of this study, which prove that the range in indices of refraction corresponds to the range in iron

TABLE 3.—*Chemical analyses for iron and water and determination of indices of biotite*

[*A*, book biotite from unaltered quartz monzonite; *B*, leafy biotite from biotite-albite-quartz-orthoclase facies of altered quartz monzonite. Analyst, M. L. Lindberg]

	A	*B*	
		Crystals 1–3 mm in diameter	Crystals less than 1 mm in diameter
Total Fe as Fe_2O_3	21.36	14.24	11.29
Total H_2O	3.00	2.92	2.54
Indices of refraction:			
Alpha	1.586	1.565	1.555
Beta	1.639	1.617	1.607
Gamma	1.639	1.617	1.607

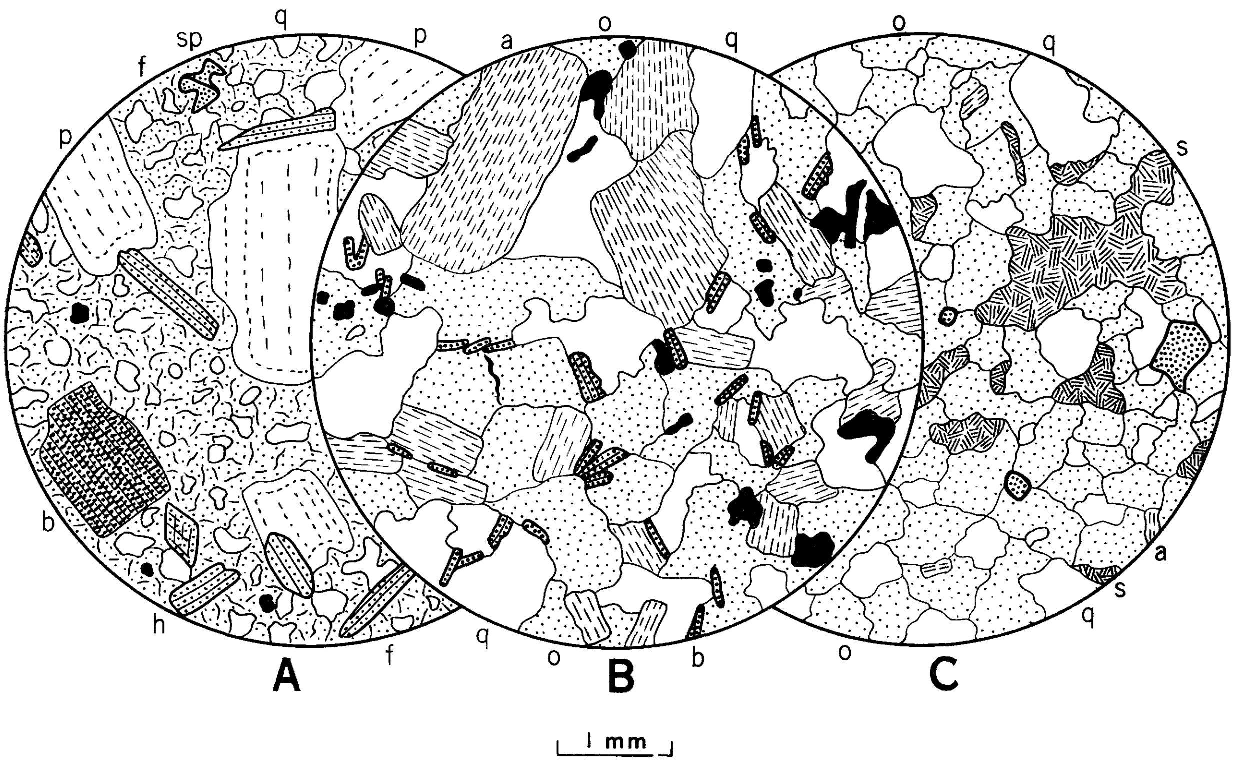


FIGURE 8.—Microdrawings of analyzed unaltered and altered quartz monzonite, Bagdad area, Arizona. *A*, Unaltered quartz monzonite; *p*, plagioclase; *q*, quartz; *b*, biotite; *h*, hornblende; *f*, orthoclase and plagioclase; *sp*, sphene; black areas, magnetite. *B*, Biotite-albite-quartz-orthoclase facies; a, albitic plagioclase; *o*, orthoclase, *q*, quartz; *b*, leafy biotite; black areas, chiefly chalcopyrite, some pyrite. *C*, Quartz-orthoclase-sericite facies; *s*, sericite; *o*, orthoclase; *a*, albite; *q* quartz; heavily stippled areas with black borders, jarosite.

content; plotting of β against total iron results in a straight-line graph. The water content is about the same in the micas from altered and unaltered facies which proves that the leafy mica is biotite rather than hydrobiotite or vermiculite, and the iron content indicates it is not phlogopite. Schwartz (1947) determined the hydrothermal brown mica at Bingham and Ely to be biotite.

The plagioclase in the altered facies ranges in composition from albite to sodic oligoclase. Sericite in scattered minute flakes or coarser clusters appears in some of the albitic feldspar. Sericite is found also in clusters between quartz and orthoclase crystals and forms some veinlets in the rock. A little sericite is interleaved with leafy biotite; it may represent simultaneous formation or alteration of biotite to sericite, or the reverse. The index of refraction of β of a number of tested specimens of the sericite is 1.595 ± 0.005. Lovering (1941, p. 237) has reported a micaceous mineral of lower index and birefringence than sericite in hydrothermally altered rocks, which he provisionally called hydrous mica. The sericite from Bagdad shows the polarization colors associated with this mineral, and the index of refraction substantiates this conclusion.

Quartz and orthoclase are more abundant and coarser grained in the sulfide-bearing rocks than in the unaltered rock (fig. 8*B*, *C*). Along some of the mineralized fractures, quartz and orthoclase appear as veinlets containing stubby prisms of apatite. Stubby crystals or granular aggregates of rutile, derived from sphene and biotite, occur in the altered rock, rarely associated with sericite and more commonly with quartz and orthoclase. Chlorite is a minor alteration product of the biotite.

QUARTZ-ORTHOCLASE-SERICITE FACIES

Prominent outcrops of quartz-orthoclase-sericite rock stand out as ribs and irregular masses in the central stock at Bagdad, but in total volume, comprise only a minor part of the altered quartz monzonite. The ribs, generally 10 to 20 feet wide, have northeast and northwest trends parallel to the main structural elements of the stock. The quartz-orthoclase-sericite facies is not limited to the copper-bearing part of the stock but is well exposed in the western margin of the stock.

Two varieties of quartz-orthoclase-sericite facies were recognized. One shows a complete loss of the original seriate or porphyritic texture (fig. 8*C*); the rock consists of an interlocking aggregate of quartz, orthoclase, and minor albite that contains clusters and veinlets of sericite. The other variety contains relict plagioclase phenocrysts altered to albite heavily loaded with sericite and separated by clear granular orthoclase and quartz. Locally a small amount of leafy biotite is present.

HYPOGENE METALLIZATION

Hypogene metallization was characterized chiefly by the deposition of pyrite, chalcopyrite, molybdenite, and subordinately by deposition of galena, sphalerite, and barite. From the evidence available, it is believed that alteration of the quartz monzonite was contemporaneous with the deposition of the sulfides. In places veinlets of quartz and orthoclase containing scattered sulfides are distinct from and cut the biotite-albite-quartz-orthoclase facies, but elsewhere these veinlets grade into this facies. Some clusters of magnetite in association with leafy biotite suggest that magnetite was formed by recrystallization of iron released during the alteration of book biotite to leafy biotite. But, in some specimens, magnetite in quartz-orthoclase veinlets carrying sulfides implies that some magnetite was deposited in fractures. In the main, magnetite is rare.

Pyrite and chalcopyrite are usually found as disconnected anhedral granules, but in some specimens pyrite is euhedral. The granules are generally in chainlike pattern, which indicates that a fracture guided deposition, but the associated quartz and orthoclase grew into the host rock, "healing" the original fracture. Some isolated grains of pyrite and chalcopyrite cannot be related to fractures and are disseminated, but they are always associated with quartz and orthoclase. In a few specimens, the pyrite or chalcopyrite granules touch, forming short continuous sulfide veinlets. Rarely are pyrite and chalcopyrite in contact, and no positive evidence is available to suggest their age relationship, but confinement to a single fracture that contains no evidence of banding or reopening is indicative of contemporaneous deposition.

The precise age relationship of sericite to pyrite and chalcopyrite is uncertain. Some chains of disconnected sulfide granules are connected by minute fracture lines with sericite or occur in zones of microbreccia with or without sericite. Some quartz-orthoclase-sulfide veinlets contain sericite, but in others sericite is absent. Under a high magnification, rosettes and individual crystals of sericite penetrate chalcopyrite without any of the obvious textures of replacement of the sericite, which suggests that locally, at least, some sericite may be slightly younger than chalcopyrite, contemporaneous with chalcopyrite, or older and inert to the sulfide-depositing solutions. This evidence indicates that, in general, sericite, pyrite, and chalcopyrite were contemporaneous.

Similarly, the precise age relationship of sericite to orthoclase is uncertain. Rarely, veinlets containing sericite cut through quartz and orthoclase, but in most places, the sericite is present as nests interstitial to quartz and orthoclase. No evidence was observed either of clear-cut replacement of orthoclase by sericite or of the reverse. The overall picture suggests that the hypogene silicates and sulfide minerals were formed in one stage and no definite sequence of formation of these minerals can be established.

Quartz-pyrite-chalcopyrite veins cut the altered and metallized quartz monzonite; most of these veins are small, one-eighth to 1 inch wide, locally widening to 3 inches. Two veins, however, are 1 to 2 feet wide. These quartz-sulfide veins are composed of glassy to white vuggy quartz in which the pyrite and chalcopyrite appear as scattered aggregates in the vein or lining vugs. Some sericite is present in the quartz and along the vein walls. Sphalerite and galena appear as small aggregates in the wider quartz veins, in one place associated with cream-colored barite. Clear, white calcite crystals were observed in a few of the veins. The age relationship of these minor minerals to the pyrite and chalcopyrite of the veins is uncertain, but probably they were late in the sequence.

Molybdenite-quartz-orthoclase-pyrite veins cut the quartz-pyrite-chalcopyrite veins, which indicate that the molybdenite is younger than the chalcopyrite. Locally, molybdenite is found in quartz-pyrite-chalcopyrite veins for a foot or more from the intersection with the younger molybdenite-bearing veins, and if only that part of the vein were visible, molybdenite might appear to be contemporaneous with chalcopyrite. In places, the molybdenite is only a thin film along fractures associated with much quartz, but elsewhere, molybdenite crystals a quarter of an inch in diameter were deposited along both margins of the vein. In some veins, molybdenite streaks ramify throughout the quartz. Some of the molybdenite occurs between quartz crystals, but in other places it has followed and replaced microbrecciated quartz. Locally, sericite is abundant and appears essentially contemporaneous with molybdenite.

It seems probable that the quartz-pyrite-chalcopyrite veins mark the course of original channels through which the hypogene solutions passed to the minor fractures, producing the alteration of the quartz monzonite and forming the hypogene silicates and sulfides. These channels presumably were clogged by deposits from quartz-rich solutions during the final stage of mineralization, but in the wider veins, late solutions deposited the galena and sphalerite.

Examinations of many polished surfaces of the primary sulfides collected from different parts of the

Bagdad mine give a general impression that the total content of sulfide per unit volume is about the same, irrespective of the grade of copper. But in the areas where the copper is lower grade, the amount of pyrite exceeds chalcopyrite, whereas the opposite is true where the copper is higher grade.

CHEMICAL AND MINERALOGIC CHANGES

Chemical analyses of unaltered and altered quartz monzonite are given in table 4. Sample *A*, unaltered quartz monzonite, was collected in a creek bed southeast of Bagdad (pl. 3) from a body of quartz monzonite separated from the main stock by a belt of pre-Cambrian rocks. Whether or not these two bodies of quartz monzonite connect in depth is debatable. However, this sample was collected from the outcrop nearest to the Bagdad mine, that represents rock that is unaltered by hypogene action and that also shows little or no indications of weathering. Comparisons of thin sections of this rock with those of other specimens of unaltered rock farther from the Bagdad mine indicate this rock is typical of the original quartz monzonite. Sample *B* is of protore and was collected in the Bagdad mine from the undercut level in the primary-sulfide zone. It contains a little more copper than average for the protore, but the hypogene alteration in this specimen is typical of the biotite-albite-quartz-orthoclase facies of hypogene alterated quartz monzonite. Sample *C* was collected at the surface over the Bagdad mine and represents ribs of rock of the quartz-orthoclase-sericite facies. Some jarosite represents altered pyrite; but the sample shows no other effect of supergene alteration.

TABLE 4.—*Chemical analyses of unaltered and altered quartz monzonite*

[*A*, unaltered quartz monzonite, from outcrop southeast of Bagdad mine; *B*, biotite-albite-quartz-orthoclase facies of altered quartz menzite, protore from Bagdad mine; *C*, quartz-orthoclase-sericite facies of altered quartz monzonite, from surface over Bagdad mine. Analyst, A. C. Vlisidis]

	A	*B*	*C*
SiO_2	64.49	67.26	68.41
Al_2O_3	17.43	15.89	16.57
Fe_2O_3	1.84	.88	1.16
FeO	1.65	1.44	.53
MgO	1.93	2.30	.43
CaO	3.47	1.18	.16
Na_2O	4.48	3.10	.78
K_2O	2.38	3.94	8.37
H_2O-	.44	.23	.14
H_2O+	.90	1.07	1.66
TiO_2	.46	.37	.32
P_2O_5	.19	.17	.13
MnO	.09	.04	None
CO_2	.12	.04	.06
S		1.35	
SO_3			1.10
CuO		1.05	
	99.87	100.31	99.82
O=S		.68	
		99.63	
Specific gravity, 30/4 (powder)	2.75	2.65	2.68
Specific gravity (bulk)	2.7	2.6	2.6

Spectrographic analyses for the minor elements in the same three samples are given in table 5. The approximate mineral composition of these three samples, as shown in table 6, was calculated from the chemical analyses, modified in part by using modal composition determined by thin-section traverses.

TABLE 5.—*Spectrographic analyses of the minor elements in unaltered and altered quartz monzonite*

[*A*, unaltered quartz monzonite; *B*, biotite-albite-quartz-orthoclase facies of altered quartz monzonite; *C*, quartz-orthoclase-sericite facies of altered quartz monzonite. Analyst, K. J. Murata]

	A	*B*	*C*		*A*	*B*	*C*
Cu	0.004	1.0±	0.01	Zr	0.01	0.01	0.02
Ni	.002	.002		Pb	(1)	(1)	(1)
Co	.001	.002		B			.001
Ag		.0003	.0002	Be	(2)	.0004	Tr.
Mo		.002	.005	Ba	.05	.03	.01
Cr	.002	.001	.001	Sr	.08	.05	.08
V	.008	.008	.006	Y	.003	.003	.003

[1] Trace for Pb, element was detected, but in amounts less than 0.0001 percent.
[2] Trace for Be, element was detected, but in amounts less than 0.0004 percent.
Looked for but not found: Zn, Cd, W, Bi, Au, Pt, Re, In, Tl, Ge, Sn.

TABLE 6.—*Approximate mineral composition of unaltered and altered quartz monzonite*

[*A*, unaltered quartz monzonite; *B*, biotite-albite-quartz-orthoclase facies of altered quartz monzonite (protore); *C*, quartz-orthoclase-sericite facies of altered quartz monzonite]

	A	*B*	*C*
Quartz	20.0	28.0	33.0
Orthoclase	14.0	23.0	43.0
Oligoclase-andesine	54.0		
Albite		35.0	7.0
Sericite		2.0	13.5
Biotite	3.5	8.0	
Hornblende	6.5		
Apatite	.3	.3	.2
Sphene	1.2		
Rutile		.35	.3
Magnetite	.3	.05	
Calcite	.2		
Pyrite		.9	
Chalcopyrite		2.4	
Jarosite			3.0

In order to compare the losses and gains of the principal chemical constituents the amounts in milligrams per cubic centimeter for each of the three samples were calculated, and the results are shown graphically on figure 9, which, with figure 10, compares the losses and gains of the principal constituents at Bagdad with those of certain other porphyry copper deposits. The changes in mineralogic composition in the alteration of one cubic centimeter of rock are shown on figure 11. The loss of lime and soda (fig. 9) in the altered rocks is significant, indicating that albitization of the plagioclase is the result of greater leaching of the lime, as suggested by Gilluly (1942, p. 290) for the deposit at Ajo. Magnesia shows a slight increase in the protore (sample 2), but a marked decrease in quartz-orthoclase-sericite facies (sample 3). A systematic decrease in the total iron content indicates replacement of iron by magnesia in the newly formed leafy biotite, as most of the iron in sample 2 is found in the pyrite and chalcopyrite. Potash is the only constituent that shows marked increase in

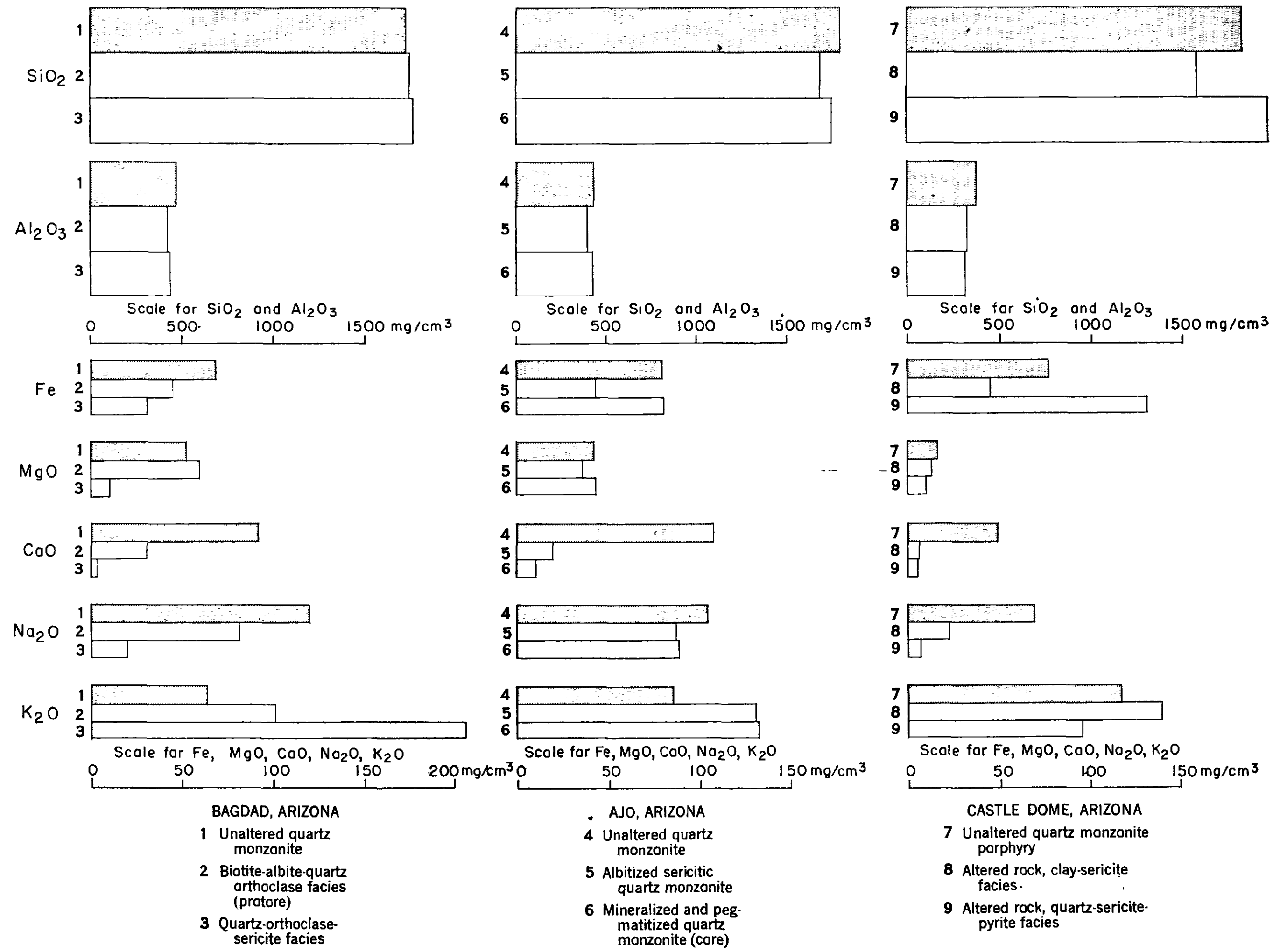


FIGURE 9.—Graph showing the loss and gain of principal rock constituents by rock alteration at Bagdad, Ajo, and Castle Dome, Ariz. Ajo analysis from Gilluly (1946, p. 30). 4, analysis 4, bulk density 2.7; 5, analysis 6, bulk density 2.5; 6, analysis 7, bulk density 2.65. Castle Dome analyses from Peterson and others, (1946, p. 836). 7, average of analyses 1 and 2; 8, analysis 4; 9, analysis 5.

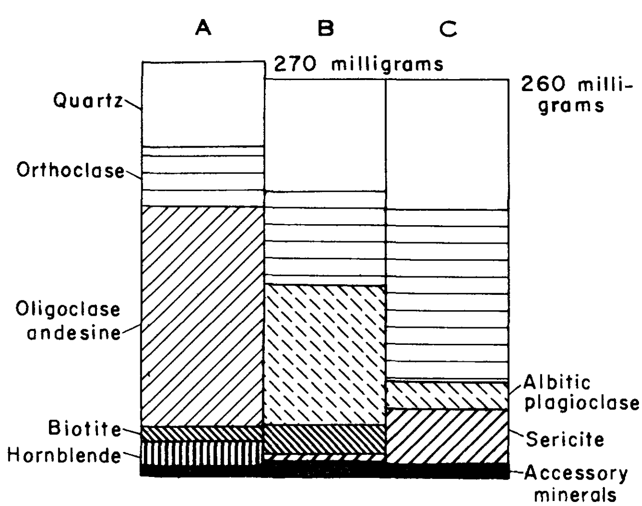


FIGURE 11.—Graph showing mineralogic changes in alteration of one cubic centimeter of quartz monzonite, Bagdad area, Ariz. *A*, Unaltered quartz monzonite. *B*, Biotite-albite-quartz orthoclase facies of altered quartz monzonite. *C*, Quartz-orthoclase-sericite facies.

both altered facies, and this fact is reflected mineralogically by increases in orthoclase and sericite which takes up alumina and silica released from the alteration of plagioclase (Butler, 1932, p. 21). There is a slight decrease in alumina in the altered rocks (fig. 9). The silica content increased very slightly in the protore and quartz-orthoclase-sericite facies. Little loss of titania content is indicated, and the rutile in the altered quartz monzonite must represent recrystallization of titania derived from sphene and biotite in the original rock. Although apatite occurs as conspicuous crystals in the altered facies, as contrasted to the small crystals in the unaltered rock, the analyses show no gain in phosphorus pentoxide, indicating that apatite is only recrystallized and redistributed in the altered rock.

The spectrographic analyses (table 5) show that in the unaltered quartz monzonite, sample *A*, the copper content is 0.004 percent; this figure probably gives the

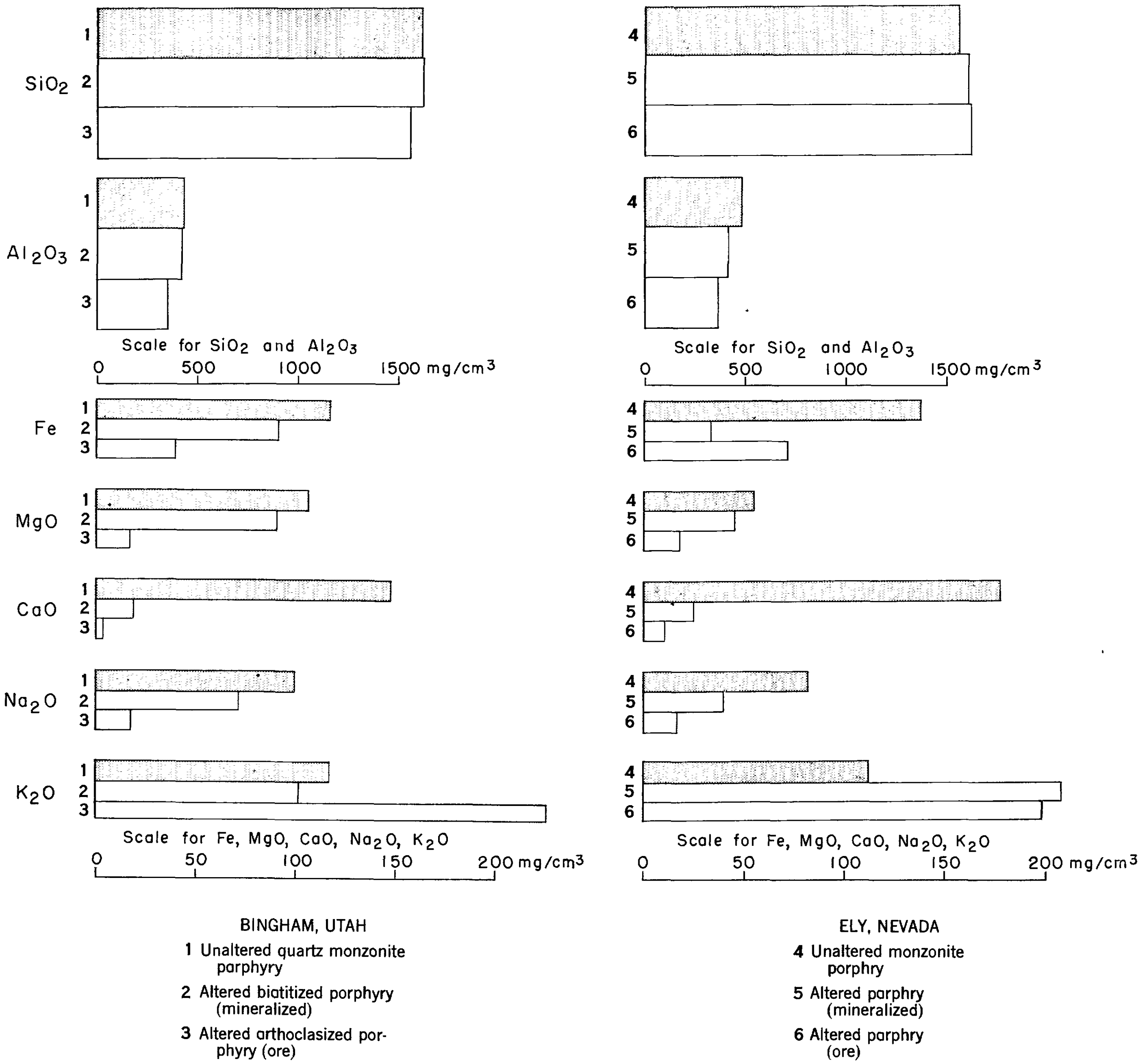


FIGURE 10.—Graph showing the loss and gain of principal rock constituents at Bingham, Utah, and Ely, Nev. Bingham analyses from Butler (1920, p. 166). 1, Analysis 1; 2, analysis 2; 3, analysis 3. Ely analyses from Spencer (1917, p. 57). 4, Analysis 35; 5, analysis 102; 6, analysis 153.

order of magnitude of copper content in the quartz monzonite stocks beyond the zones of mineralization. These analyses show that barium is leached in the altered rocks, and the small amount of barite observed in some of the veins may have been derived from the barium leached from the host rock. In contrast, there is as much strontium in the quartz-orthoclase-sericite facies as in the unaltered rock.

Molybdenite (MoS_2) is a common minor constituent of most porphyry copper deposits. In the Bagdad mine, it occurs sporadically in the protore and in the chalcocite zone, and it has been separated from the copper concentrates at various times. The determination of grade of molybdenite in a porphyry copper ore is difficult, owing to variations in its distribution in the ore and the small quantity present. When the molybdenite was recovered at Bagdad in 1944–45, several assays of the mill heads averaged approximately 0.02 percent MoS_2 (0.012 percent Mo). In samples *B* and *C*, containing no detectable molybdenite (table 4), the spectrographic analyses (table 5) show 0.002 and 0.005 percent of molybdenum. The 0.02 percent

MoS_2 content of the Bagdad mill heads is only half that at Bingham, Utah, but twice that at Chino, N. Mex. (Vanderbilt, 1942, p. 60).

Recoverable gold and silver may be of considerable economic importance in the porphyry copper deposits because of the large daily tonnages of ore mined. Locke (1933, p. 616) has tabulated the ratios of copper to gold and to silver for five porphyry-copper deposits to which the Bagdad and Castle Dome ratios are added for comparison in the accompanying tabulation. The amount of gold recovered at Bagdad is very small, only 40 ounces to 1945, and no gold was found in the samples analyzed spectrographically. Silver was detected in samples *B* and *C* (0.0003 percent and 0.0002 percent), which corresponds to 0.09 and 0.06 ounce per ton. These amounts are appreciably higher than the grade of recoverable silver, 0.02 ounce per ton, a figure based on the recovery of 53,981 ounces of silver to the end of 1945.

Ratio of copper and gold and silver in selected porphyry copper deposits

[After Locke except for Bagdad and Castle Dome]

	Cu:Au	*Cu:Ag*
Bingham	40, 000	4, 000
Ely	30, 000	10, 000
Ray	1, 000, 000	15, 000
Miami	1, 000, 000	15, 000
Ajo	70, 000	6, 500
Castle Dome [1]	840, 000	12, 400
Bagdad	12, 000, 000	9, 000

[1] Furnished by N. P. Peterson.

It appears definite that the mineralizing solutions carried appreciable quantities of sulfur, copper, and potash, and minute quantities of molybdenum, lead, zinc, and silver. The potash may have been leached from deeper rocks rather than having been derived from the same magmatic source as the other metals and sulfur. The removal of lime, soda, and iron from the altered rocks is definite; in the quartz-orthoclase-sericite facies, magnesia is also removed. Their ultimate place of deposition is unknown. Lateral migration from the center of mineralization is not indicated by any pronounced enrichment in pyrite or carbonates. Possibly these constituents were deposited above the stock in rocks that have been removed by erosion.

COMPARISON WITH OTHER DISSEMINATED COPPER DEPOSITS

Schwartz (1947) has given an excellent summary of the mineralogic changes associated with different disseminated-copper deposits of western United States. He has noted that several kinds of alteration can be recognized in each deposit, but in a particular deposit one type may be dominant, such as the introduction of orthoclase at Ajo, Ariz., (Gilluly, 1942). Argillic alteration was first described at Castle Dome, Ariz. (Peterson and others, 1946) and it has been recognized by Schwartz at Morenci and San Manuel, Ariz., and Chino, N. Mex. However, argillic alteration was not recognized at Bagdad. Recrystallization of mafic minerals to biotite was recognized at Bingham, Utah; Ely, Nev.; and San Manuel, Ariz., and this type of alteration is important at Bagdad. The introduction of orthoclase, so strikingly illustrated at Ajo, is of major importance at Bagdad, but the introduced orthoclase is not so important quantitatively at Bagdad nor do the orthoclase crystals attain the dimensions (pegmatitic in part) of those at Ajo. The introduction of orthoclase is also important at Ely and Bingham. Sericitic alteration appears to be common to all the porphyry copper deposits. The alteration at Bagdad resembles that at Ely and Bingham most, because orthoclasic and biotitic alterations are common to all three.

Chemical analyses of unaltered and altered host rocks of porphyry copper deposits in western United States are available only for those of Castle Dome, Ajo, Bingham, and Ely. In order to compare the losses and gains of the principal constituents at Bagdad with those of other porphyry copper deposits, graphs have been prepared that show the amount in milligrams per cubic centimeter of unaltered and altered rocks (figs. 9 and 10). No analyses of samples are available from Chino, N. Mex., or Morenci, Ariz., where argillic alteration is common, but one analysis of the clay-sericite facies of host rock at Castle Dome gives some chemical data on argillic alteration (fig. 9, no. 8).

The losses and gains in silica in these deposits are not appreciable, except for the quartz-sericite facies at Castle Dome, which, however, is not of great areal extent (Peterson, and others, 1946, p. 827). The excess of silica may have been derived from the more widespread clay-sericite facies which shows a loss in silica (fig. 9). Except at Ajo, a slight loss of alumina in the altered rocks indicates some leaching during alteration. Losses and gains in iron are shown in terms of the element iron rather than in terms of the ferrous and ferric ions or of iron sulfide in order to show the variations in total iron content. The pyrite-bearing quartz-sericite facies at Castle Dome shows an increase in iron as contrasted to the unaltered host rock, but this facies occupies a limited area, and the wide-spread clay-sericite facies shows a loss in iron. At Ajo, leaching of iron is indicated in the albitized sericitic quartz monzonite host rock, but in sulfide ore the iron content is the same as in the unaltered quartz monzonite (fig. 9, nos. 5 and 6). In the other deposits, iron is leached in the altered facies, even though parts of these facies represent protore or ore (fig. 9, no. 2; fig. 10, nos. 3

and 6). Magnesia increases in the protore at Bagdad (fig. 9, no. 2), and remains about the same in the Ajo ore (fig. 9, no. 6). In the other deposits, the amount of magnesia leached from the altered rocks differs. All deposits show a consistent loss in lime, and, except for Ajo, noticeable loss in soda. Apparently all albitization associated with the formation of porphyry copper deposits results from loss in lime rather than from addition of soda. Except for the quartz-sericite facies at Castle Dome (fig. 9, no. 9), and the biotitized porphyry at Bingham (fig. 10, no. 2), potash content increases in the altered rocks, markedly in the quartz-orthoclase-sericite facies at Bagdad (fig. 9, no. 3), in the orthoclasized porphyry at Bingham (fig. 10, no. 3), and in both samples of altered rock from Ely (fig. 10, nos. 5 and 6). The graphs also show that the original content of potash in the host rock at Bagdad is less than that in any of the other host rocks.

Lopez (1939) describes the alteration at Chuquicamata, Chile, and includes a chemical analysis of the unaltered host rock and five analyses of altered rocks. Bulk specific gravity determinations are not given so calculations of milligrams per cubic centimeter of rock cannot be made. No biotitic alteration was recognized and magnesia was leached in all altered facies. Apparently the sericitic and siliceous facies show some gains in silica. Otherwise, the analyses are similar to those of the deposits of western United States; that is, iron, lime, and soda, are leached and potash increases.

If any general statements can be made about the porphyry copper deposits for which we have chemical data, they are: lime is more readily leached than soda during alteration, potash is usually added, magnesia may be added or a slight amount is leached in some facies, but definitely magnesia is leached in other facies. The iron content does not increase, except locally, and iron generally is leached even in sulfide ore. Silica and alumina are not appreciably changed during alteration. Perhaps the increased quartz content in the altered rocks has formed by release of silica from other minerals during alteration.

SUPERGENE MINERALIZATION

CHALCOCITE ZONE

A typical chalcocite blanket has been formed by supergene enrichment in the hypogene mineralized quartz monzonite and is located to the northeast of Copper Creek and between Copper Creek and Sanders Mesas. Exploratory churn-drill holes have given a general picture of its distribution, grade, and thickness, and the best known part of the blanket (west ore body, fig. 22) was mined by the Bagdad Copper Corp. during the time of our studies (1943–45). The blanket has formed by downward movement of copper-bearing solutions, which have replaced chalcopyrite and pyrite with chalcocite, and left a leached zone above, in places as much as 350 feet thick. Figure 12 shows assays of material from representative churn-drill holes that clearly demonstrate the enrichment in copper content in the blanket compared with the underlying primary-sulfide zone or protore, or with the leached zone above. In places in the leached zone, or capping, some concentration of ozidized copper minerals, chiefly malachite and chrysocolla, has taken place, but generally the copper content in the capping is less than in the protore.

Typical chalcocite ore consists of grains of gray chalcocite 1 millimeter or less in diameter occurring along fractures or as disseminations in the quartz monzonite. Thin sections reveal little change in the quartz monzonite, except that some of the feldspars are partly clouded with minute indeterminate spots of clay(?), which may account for the dull luster of the rock. Biotite and sericite are unaltered. Microscopic studies of the ore minerals in the chalcocite zone reveal that chalcocite replaces chalcopyrite in preference to pyrite. Covellite, observed as films on some chalcopyrite, may represent a transitory stage in the replacement of chalcopyrite by chalcocite. In average chalcocite ore the pyrite may be replaced partially, or it may show no signs of replacement. Indeed, no polished surfaces of disseminated chalcocite ore failed to reveal some pyrite. However, in the wider quartz-pyrite-chalcopyrite veins, where postmineral faulting increases permeability, both sulfides are replaced by chalcocite near the top of the blanket, and sooty chalcocite is rather common.

Along some of the fractures and faults, aggregates and films of greenish to yellow-brown clay are present in the leached and chalcocite zones, but not in the protore. The clay consists of a mixture of kaolinite and a member of the saponite-montmorillonite group. The clay, in part, may be transported, as adjacent silicate minerals show no sign of alteration, but along the faults the clay may be altered gouge. Because the clay is found in the chalcocite zone, it is doubtful that the clay is related to present weathering processes, but its absence in the protore suggests that the clay is of supergene origin, and possibly it formed during the period of chalcocite enrichment.

The geometry of the chalcocite blanket in the Bagdad mine is fairly well known because of the close spacing of churn-drill holes and accessible boundary drifts at the time of underground mapping. The visual study of the ore was greatly aided by systematic drift assays. Adjacent to the mine, rather close spacing of many of the exploratory churn-drill holes gave additional data for expanding the geometry of the chalcocite zone. These data have been compiled on many cross sections, and some are reproduced on figures 13–16. From the

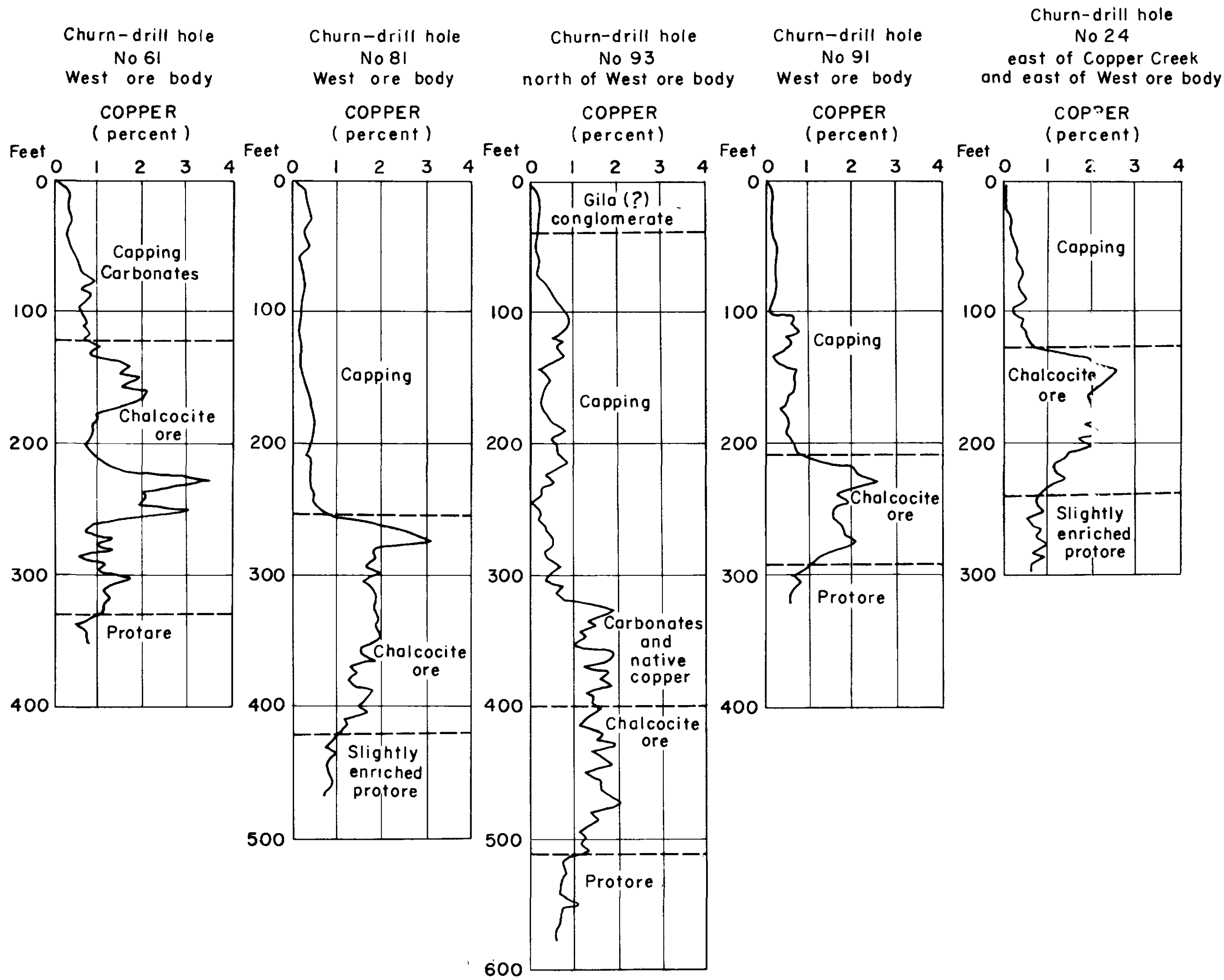


FIGURE 12.—Graphs of assays of representative churn-drill holes, Bagdad mine, Bagdad, Ariz.

cross sections, contour maps of the top (fig. 17) and the base of the chalcocite zone (fig. 18) were constructed, and from these, an isopach map was drawn (fig. 19). The cross sections show rather clearly that the top of the chalcocite zone in general, is parallel to the base of the Gila(?) conglomerate, so that the blanket, in general, dips to the north and is truncated to the south by the present erosion surface. This implies definitely that supergene enrichment took place during pre-Gila(?) time, and possibly continued during the deposition of the Gila(?) conglomerate.

Only in the northeast corner of the Bagdad mine were underground workings accessible that exposed the top of the chalcocite zone, and in the cross sections the top of the zone can only be connected from drill hole to drill hole. Actually where the top of the chalcocite zone is exposed in the underground workings, the top is somewhat irregular, and oxidation of chalcocite is rather deep along the more permeable faults and less deep along the smaller and tighter slips. The top of the chalcocite zone is marked locally by some concentration of malachite, chrysocolla, cuprite, and native copper. The base of the chalcocite zone is much more irregular, but its position could be determined in the mine with more precision because of the many openings. Actually the base of the chalcocite zone is not as sharply defined as cross sections suggest, for there is a transition from ore in which most of the sulfide granules are pure chalcocite to a zone, commonly from 10 to 20 feet thick, containing unreplaced pyrite and chalcocite coatings on chalcopyrite, and this is transitional to the primary-sulfide zone in which no chalcocite can be recognized. The selection of the base of the chalcocite zone is thus necessarily arbitrary, and will vary within limits of 10 to 20 feet, according to the viewpoint of the investigator. In this study, the base of the chalcocite

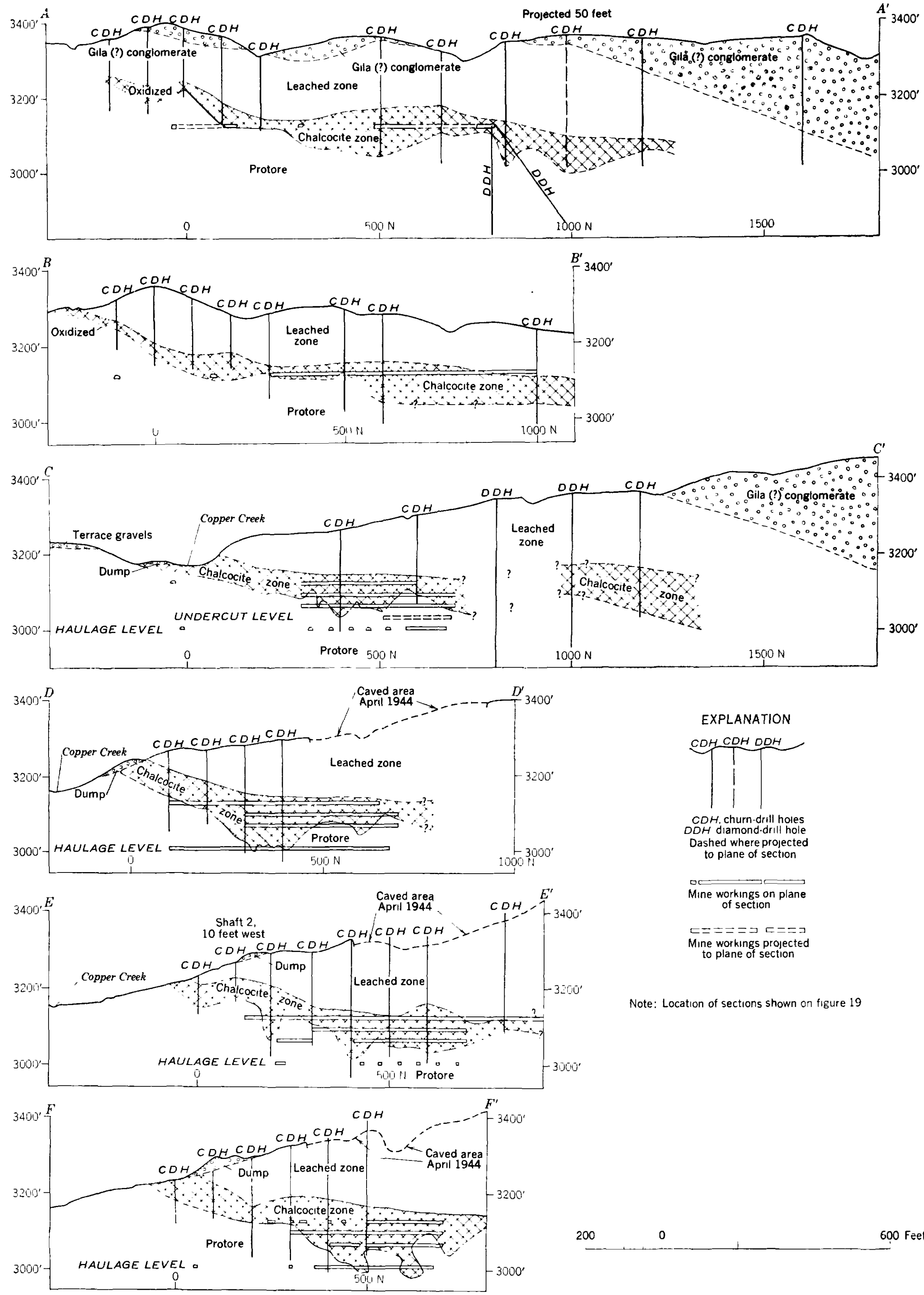


FIGURE 13.—Sections *A–A'* through *F–F'* along NS coordinate lines, Bagdad mine, Bagdad, Ariz.

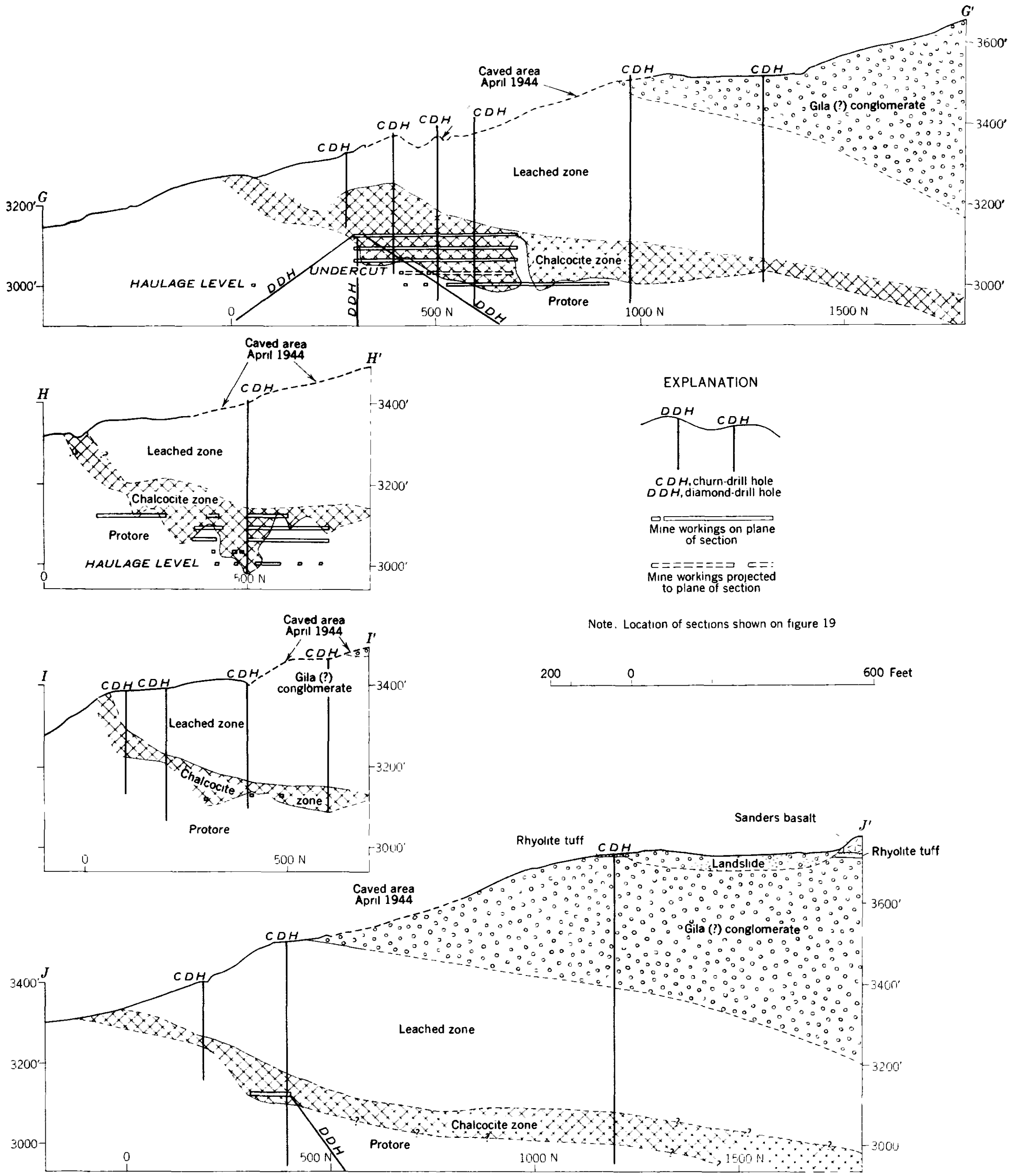


FIGURE 14.—Sections *G-G'* through *J-J'* along NS coordinate lines, Bagdad mine, Bagdad, Ariz.

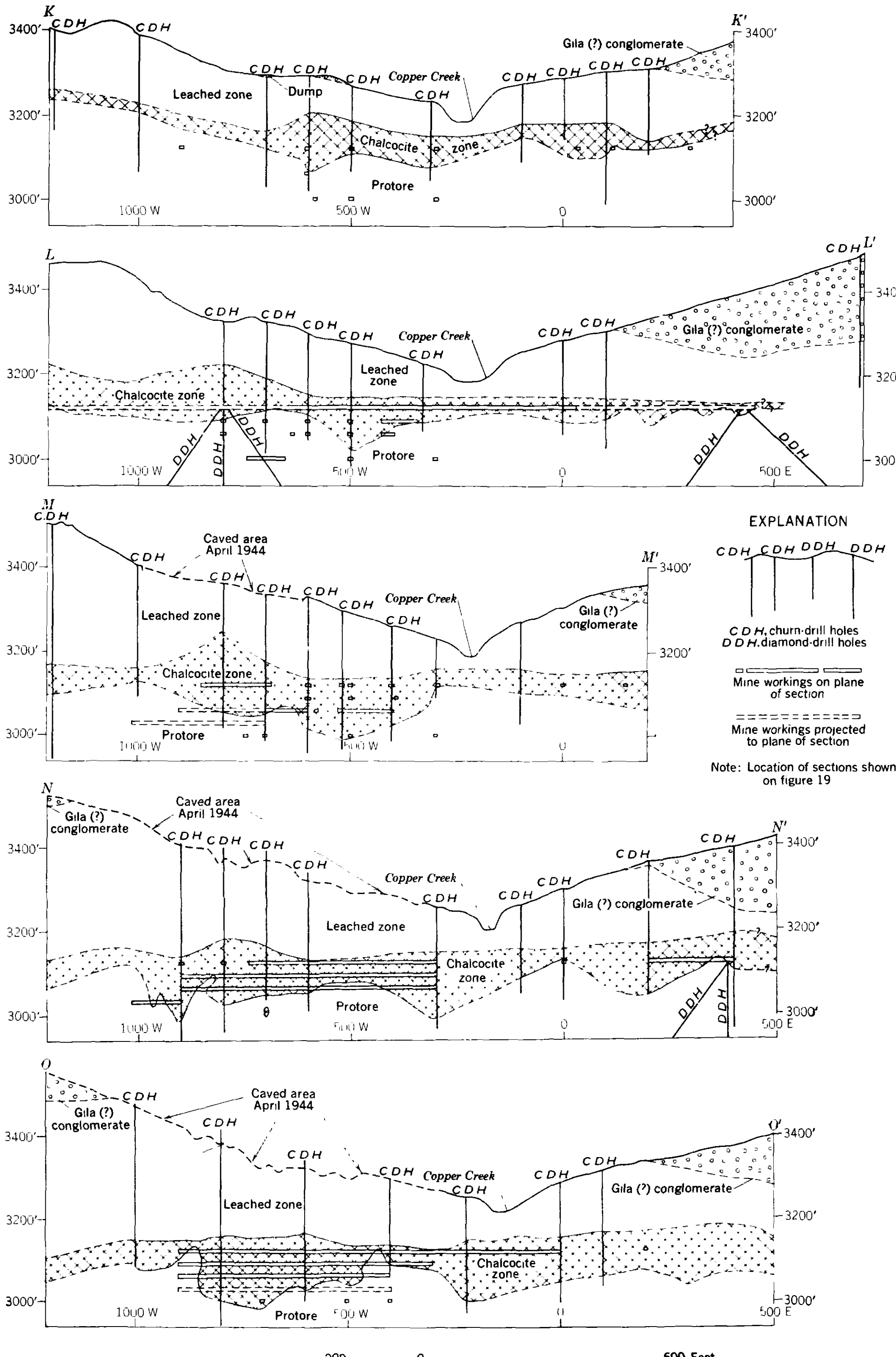


FIGURE 15.—Sections along EW coordinate lines, Bagdad mine, Bagdad, Ariz.

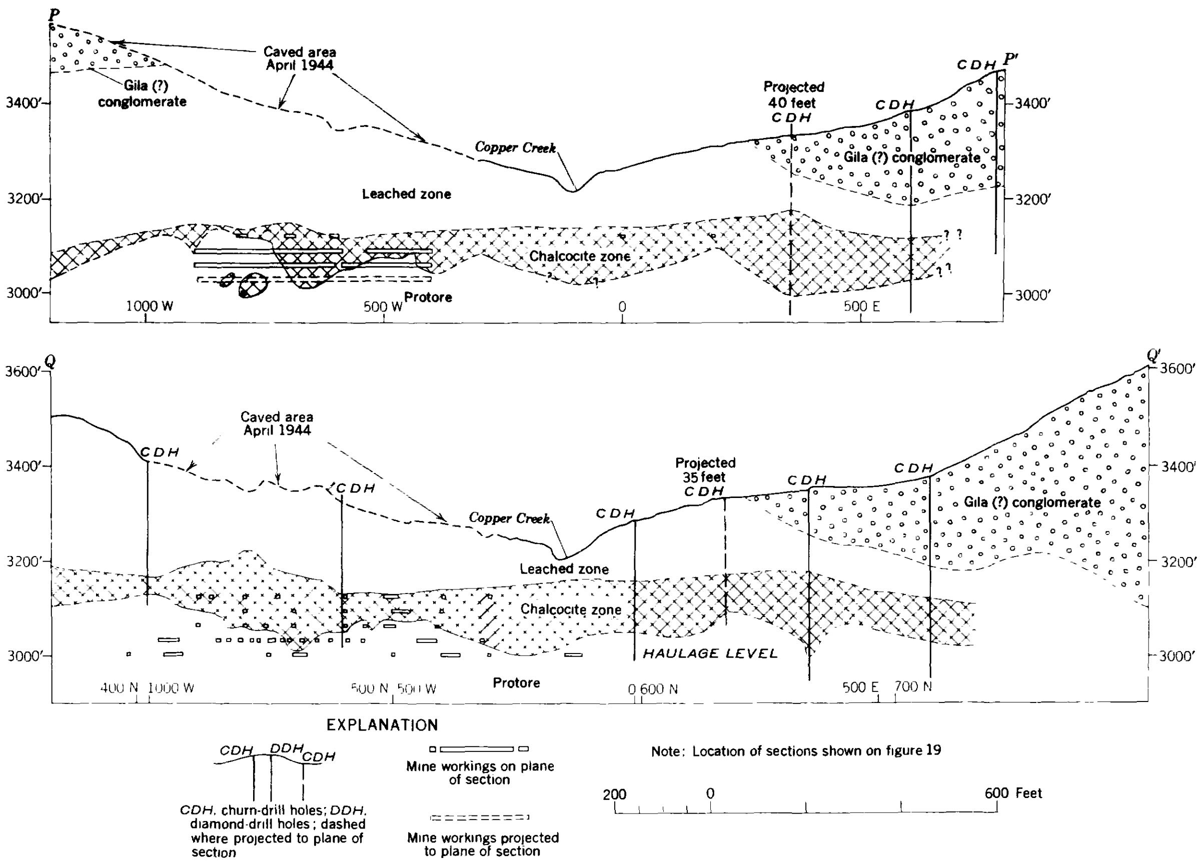


FIGURE 16.—Sections through Bagdad mine, Bagdad, Ariz.

zone was placed near the top of the transition zone in which chalcopyrite is conspicuous, containing only coatings of chalcocite. A sharp break downward in the copper content takes place from the zone in which chalcocite is the dominant sulfide to the zone in which it appears solely as coatings. In actual practice the bottom of the chalcocite zone was plotted by using a cutoff grade of 1 percent copper. Below this is a transition zone from 10 to 20 feet thick in which the grade decreases to 0.8 percent copper. In the underlying protore, where no chalcocite coatings are visible, the grade decreases to 0.7 to 0.6 percent copper. In other words, the "chalcocite zone" as used in this study applies to the zone in which there has been appreciable enrichment in copper.

The base of the chalcocite zone is very irregular (fig. 18) and there are related marked variations in thickness of the zone. It was observed underground that a relationship exists between deposition of chalcocite ore and faults, for good chalcocite ore appears on the hanging walls of the minor faults and primary sulfides appear on the footwalls. The reverse relationship was noted only in a few places. This might suggest two conclusions, (1) faulting occurred after deposition of the chalcocite, or (2) the permeability of the quartz monzonite, determined in large part by faulting, was the major factor in determining the depth at which chalcocite enrichment took place. Without denying the possibility that some faulting took place after chalcocite deposition, evidence suggests that locally such faulting took place, the measurable displacements along these faults are not great enough to explain the difference in thickness, and, furthermore, no evidence is present for such marked displacement of the top of the chalcocite zone. The larger faults in which continuity could be established have been plotted on the contour map of the base of the chalcocite zone (fig. 18) and the relationship between these faults and lower parts of the base is conspicuous. Also, a study of the isopach map (fig. 19) shows that the greatest thickness of chalcocite ore appears along these faults. In the northwest corner of the main ore body, northwest faults intersect northeast faults, and here a thick section of high-grade chalcocite ore was found. Thus, it seems clear that the faults were of great importance in increasing permeability of the quartz monzonite in allowing deeper penetration by the supergene copper-bearing solutions.

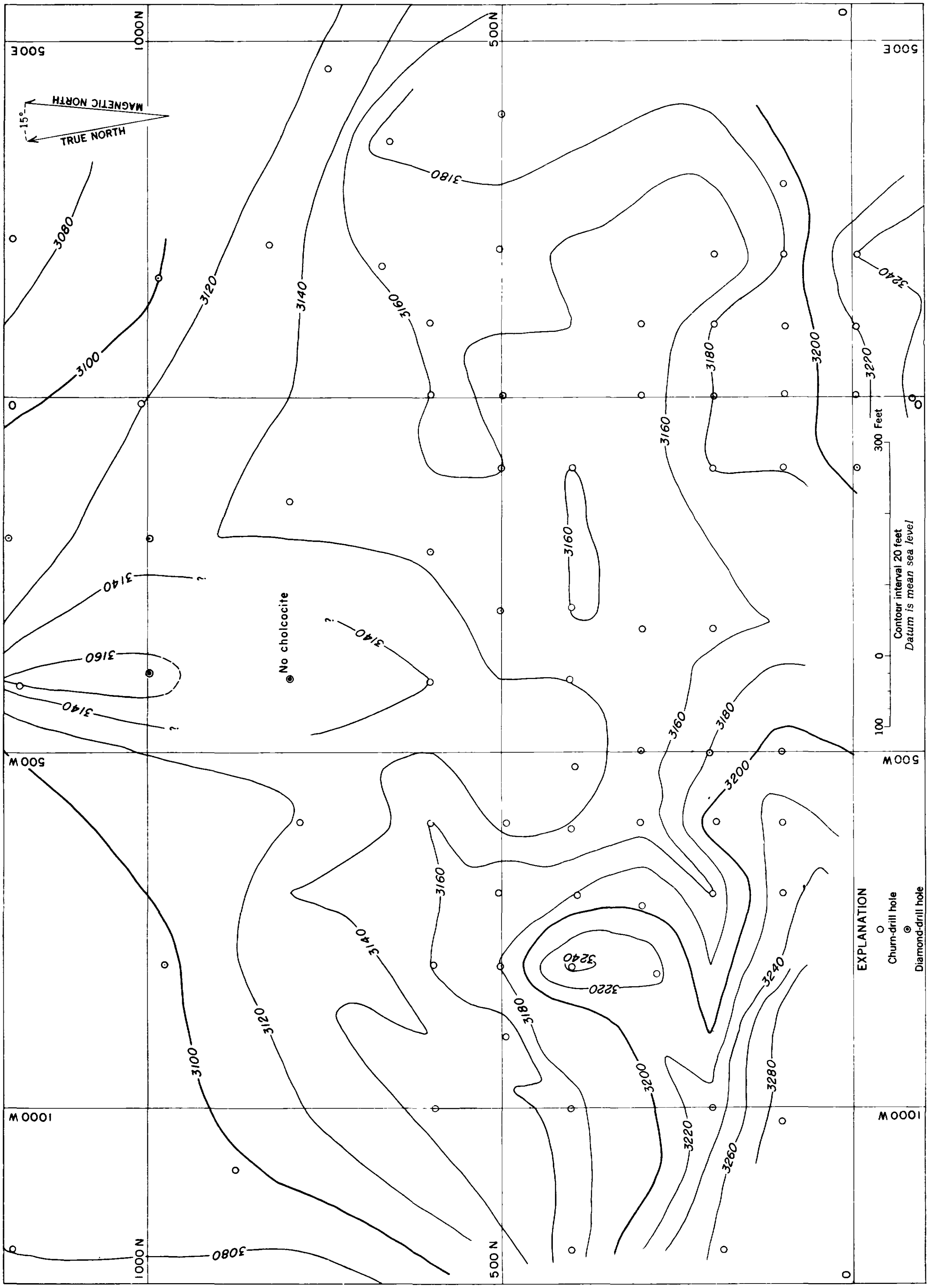


FIGURE 17.—Contour map of the top of the chalcocite zone, Bagdad mine, Bagdad, Ariz.

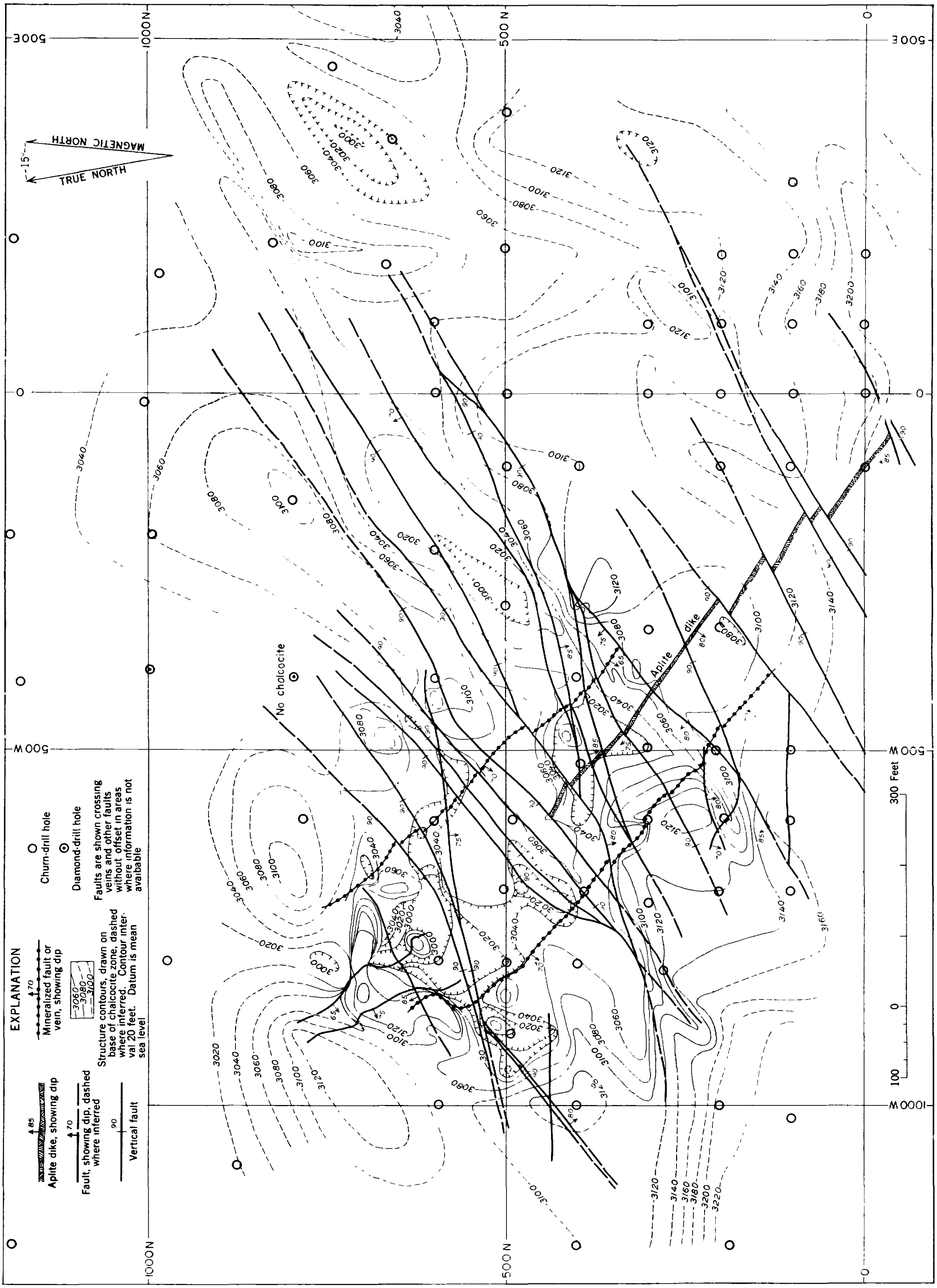


FIGURE 18.—Contour map of the base of the chalcocite zone showing major faults and veins, Bagdad mine, Bagdad, Ariz.

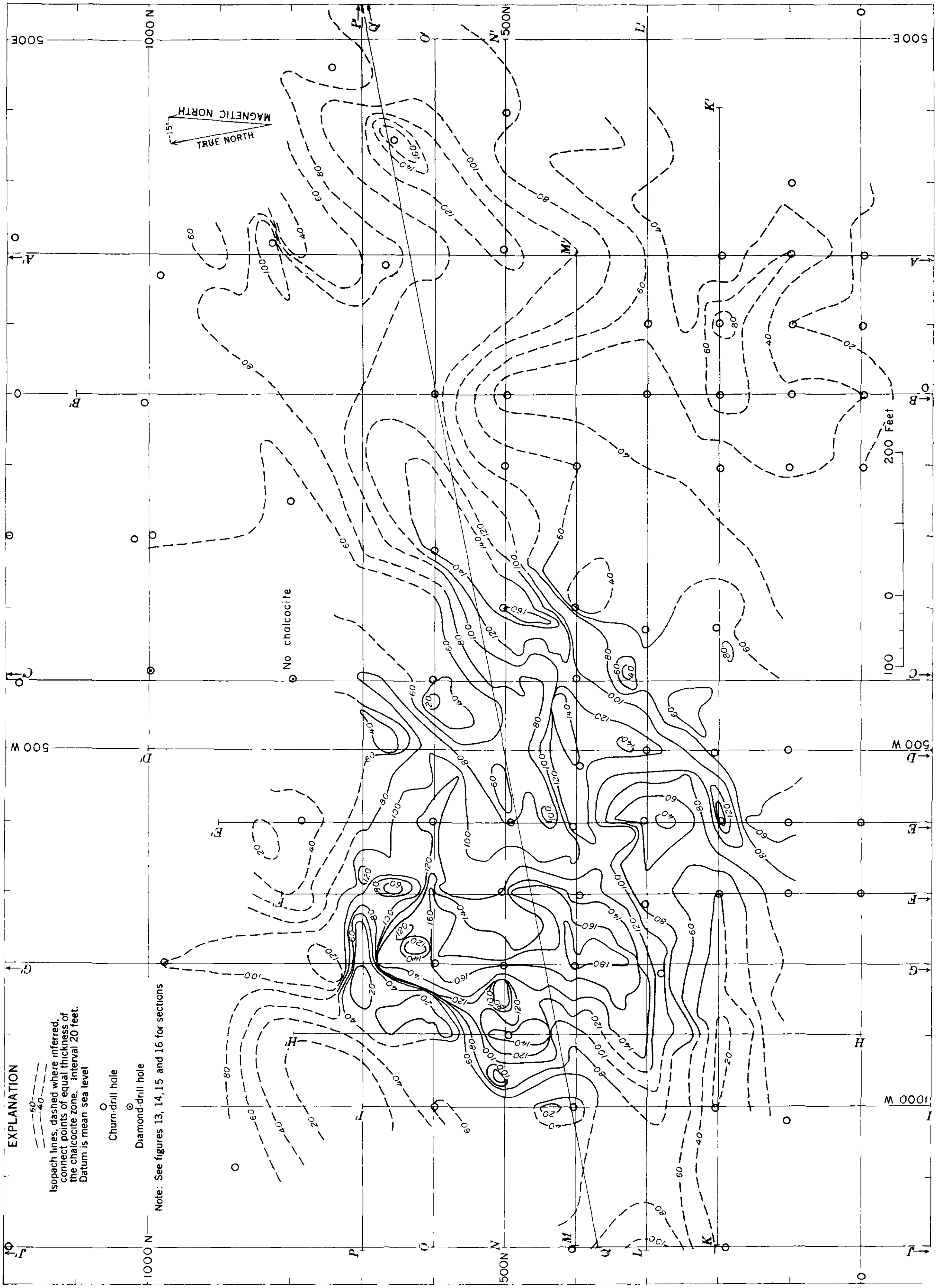


FIGURE 19.—Isopach map of the chalcocite zone, showing lines of sections (figs. 13-16), Bagdad mine, Bagdad, Ariz

Protore extends upward into chalcocite ore as "ridges" in the quartz monzonite free of faults.

The chalcocite blanket is oxidized locally, particularly along the more open faults; streaks of malachite, chrysocolla, cuprite, and native copper are common throughout the entire blanket, reducing the milling grade of the ore. Cuprite and native copper are more conspicuous where there are kidneys of chalcocite in the wider veins. Along some slips, these oxide minerals are present in the primary-sulfide zone, and brilliant red crystals of chalcotrichite (capillary cuprite) in protore occur on the haulage level. The grade of acid-soluble copper is highest near the top of the chalcocite blanket, progressively decreasing toward the base. A weighted average of 536 assays indicates that 0.174 percent acid-soluble copper is present in the ore above the undercut level, and the assays include some protore, owing to the irregularities of the base of the chalcocite zone.

The cause of the appearance of these oxidized copper minerals in the chalcocite zone is important because they are not recovered by standard flotation practice. The most obvious answer appears to be fluctuations in the water table. The recent climate in Arizona (Antevs, 1941) has not been uniform, and periods of deficient rainfall have occurred that would cause a marked lowering of the water table, whereas periods of increased rainfall would cause the water table to rise. Since underground mining began, the water table has been lowered locally, because the mine workings drain the ground water, which is pumped to the surface. It might be suggested that the early opening of the Bagdad mine in 1930 was responsible for these oxidized minerals; certainly some transportation of copper in solution has taken place, as shown by small local deposits of chalcanthite on the drift walls. An appreciable coating of gypsum also present on the older drift walls presumably was formed by calcium bicarbonate waters from the overlying Gila(?) conglomerate and Sanders basalt mixing with sulfuric acid generated by oxidation of pyrite left in the ore. However, the mine waters are essentially neutral and carry practically no copper, indicating that acid solutions carrying copper are very local in occurrence, as suggested by the paucity of chalcanthite.

It is doubtful that the extensive oxidation of the chalcocite forming malachite, chrysocolla, cuprite, and native copper has taken place since 1930, particularly as these minerals were continually exposed along watercourses by new workings on the main haulage level some distance from the two shafts that penetrate to this level. The fact that these slips contained water when reached by mining operations is indicative that the water table locally was higher than the main haulage level. The oxidation of the chalcocite and other sulfides probably took place before recent mining operations and was controlled by deep lowering of the water table in times past.

At the time of the churn drilling, the water table stood high, as revealed by the churn-drill records, and much of the chalcocite blanket was under water. In places, the water table stood high in the leached zone or in the Gila(?) conglomerate. Obviously the position of the water table immediately before present mining operations had no bearing on the deposition of chalcocite, and a high water table had the effect of protecting the chalcocite blanket from oxidation.

No direct evidence supports any particular view as to the relation of the water table to chalcocite deposition during the pre-Gila(?) time when the chalcocite blanket was formed. Spencer (1917, p. 90) has suggested that chalcocite deposition is not limited to the zone below the water table, but would take place best where the water table is deep and "that a considerable body of sulfides lying above the water table would offer the best possible conditions for the retention of the copper taken into solution by oxidizing surface waters." He also suggested that where copper-bearing solutions reached the water table, the solutions would tend to move laterally rather than downward, resulting in layering of chalcocite ore carrying more than average amount of copper. Ransome (1919, p. 176) concurred in this conclusion, adding that a "deep water table with sufficient precipitation to furnish slow percolation through the rocks above it but not enough to supply a rapid underground flow," were "the conditions favoring the maximum deposition of chalcocite." Ransome found it difficult to reconcile the irregularities of the upper and lower surfaces of the chalcocite blanket with the supposition that deposition of chalcocite took place only near the existing water table. However, Locke (1926, p. 46) has expressed the view that the top of the chalcocite zone must coincide with the water table and added that chalcocite produced above the water table could not avoid having inmixed iron oxide.

The general parallelism of the top of the chalcocite blanket at Bagdad with the pre-Gila(?) surface suggests a coincidence of the top of the blanket with the inferred position of the water table in pre-Gila time, but it is true that a fairly uniform thickness of capping might form above a chalcocite blanket lying above the water table, but at Bagdad, a more irregular top of the blanket would be expected owing to local differences in permeability. Another possibility, that which follows the thesis of Spencer and Ransome, is that after the deposition of much of the chalcocite above the water table, a marked rise of the water table, possibly coinciding with the deposition of the Gila(?) conglomerate, in time would allow leaching of any chalcocite above the water table, and its redeposition immediately below the water table. The fact that much of the richest chalcocite ore is at or near the top of the blanket might be cited as supporting evidence. This latter explanation would account for the general conformity of the top of the chalcocite zone with the base of the Gila(?) conglomerate.

LEACHED ZONE

The leached zone was examined only at the outcrops and in a few short exploratory adits, but it was possible to correlate many of these observations with the underground workings, adjacent churn-drill holes, and exposures of unaltered sulfides along Copper Creek and in some of the gulches. At the surface the weathered and leached quartz monzonite is somewhat friable, but the biotite usually gives brilliant reflections, and only locally does there appear to have been any appreciable bleaching. The feldspar is dulled somewhat, presumably by the development of some clay, but bright reflections can be obtained from many of the orthoclase crystals. Along the mineralized fractures some chemical breakdown of the silicates is indicated, and along the more open fractures, aggregates of greenish to yellow-brown montmorillonite-saponite and kaolinite, are present, similar to clay along seams in the chalcocite zone. Rarely is it difficult to recognize the original minerals of the hydrothermally altered quartz monzonite.

Our studies of the leached sulfides were aided immeasurably by the pioneer work of Locke and his associates whose studies of leached outcrops, and their finding, proved to be useful guides in the interpretation of the leached zone at Bagdad. In conformance with Locke's (1926, p. 118) nomenclature, the iron oxide formed by oxidation of the sulfides is called indigenous, if it was precipitated within the cavity formerly occupied by the sulfide. Contiguous iron oxide occurs in the gangue adjacent to a cavity formerly occupied by sulfide. Transported iron oxide has been precipitated farther from the cavity or cavities yielding the iron solutions.

Along the inner trench of Copper Creek where recent active downcutting of the canyon has taken place, the chalcocite of the veins in particular is changed to cuprite and to malachite along the margins of the veins. This product may result from a local impoverishment in pyrite so that no ferric sulfate could form to remove the chalcocite.

Over known chalcocite ore at Bagdad the iron oxide is indigenous, and each grain of original sulfide is indicated by red, more rarely black, aggregates of fluffy powdery to claylike iron oxide. Little or no transported iron oxide is present except locally. The color of the powder, or streak, is always a deep maroon, regardless of the color of the aggregate. On exposed surfaces, this "relief" iron oxide (Locke, 1926, p. 121) is in many places absent, apparently removed mechanically by the weather, but specimens broken from the outcrop reveal the reddish relief iron oxide speckling the freshly broken surfaces. Tunell (Locke, 1926, p. 106-107), on the basis of microscopic studies of capping from Morenci, Ariz., and Tyrone, N. Mex., has suggested that hematite is the important constituent of the reddish indigenous relief iron oxide and is associated with some goethite and jarosite. Lyman C. Huff, of the U. S. Geological Survey, found about 1 percent copper in the Bagdad maroon iron oxide.

Locally, over the Bagdad mine some of the iron oxide is contiguous, yellowish brown, and the indigenous iron oxide is present only as a thin red coating. This type of iron oxide residue was interpreted to indicate incomplete replacement of primary sulfides by chalcocite, so that, when oxidized, there was enough pyrite and chalcopyrite to form contiguous iron oxide.

Directly over the mine, where commercial-grade chalcocite ore occurs, jarosite pseudomorphs fill pyrite cavities in one of the more intensely silicified ribs, implying that the silicified rib was less permeable and that copper-bearing solutions never attacked the pyrite.

The leached zone over the primary sulfides pyrite and chalcopyrite is brown, owing to the universal coating of yellowish-brown transported iron oxide along the fractures, and the boundary between the oxidized chalcocite and oxidized primary sulfides, truncated by the present erosion surface, can be recognized in a broad way solely by this color difference. Where the oxidized protore is examined in detail, some iron oxide is found to be indigenous, black to yellowish brown, and yields a yellowish-brown streak. Other iron oxide is contiguous to the cavities or to indigenous iron oxide. Yellow powdery jarosite is common, appearing as fluffy aggregates or in streaks. More rarely, jarosite is orange yellow, compact and crystalline, in places occurring in cavities originally occupied by pyrite. In some of the quartz veins that carried sulfides, delicate brown-stained septa of quartz (or chalcedony) intersecting at acute angles, fill cavities from 3 to 4 millimeters across, whose walls are lined with brown or reddish-brown powdery iron oxide. Presumably this boxwork represents original chalcopyrite grains, but in much of the primary-sulfide zone, where chalcopyrite and pyrite occur as minute grains, averaging 1 millimeter in size, it is extremely difficult to differentiate oxidized chalcopyrite from oxidized pyrite. Studies were made on capping in which the grade of copper ranged from 0.2 to 0.5 percent, but no appreciable difference could be detected, except possibly that transported iron oxide was slightly more conspicuous over the rocks of lower grade copper. But this difference was too slight to warrant the division of leached protore into areas of higher and lower grade of copper.

It should be added that chalcedony veinlets are common along some of the fractures of the leached zone; in some places chalcedony coats the iron oxide. Francolite, a member of the apatite group, is found rarely as separate, tiny, hexagonal plates deposited on chalcedony or in open cavities in the indigenous yellow-brown oxide.

In the region of Alum Gulch, particularly where the alaskite porphyry is mineralized with disseminated pyrite, the iron oxide is largely of the transported type, but reddish in color, which recalls Locke's (1926, p. 115) comment that a color distinction can be used to recognize oxidized pyritic areas. In the lower course of Alum Gulch unoxidized sulfides are well exposed and consist solely of pyrite. During the dry summers, crusts of soluble sulfates and iron oxide, found along pools in Alum Gulch, indicate rapid oxidation of the pyrite. Appreciable coatings of red transported iron oxide indicate pyritic areas in which copper minerals are absent or present only in very minor quantities.

Oxidized pyrite-chalcopyrite-bearing rock and oxidized chalcocite-bearing rock can be differentiated on the basis of outcrop studies. On figure 20 the area shown as "maroon indigenous iron oxide after chalcocite" is largely oxidized chalcocite-bearing quartz monzonite; the rocks labeled "quartz monzonite" consist in large part of oxidized pyrite-chalcopyrite-bearing quartz monzonite. The boundary between the two types of oxidized rock is shown (where it could be recognized) on figure 20. The areas of "maroon indigenous iron oxide after chalcocite" east of the Hawkeye fault show the outcrop of the oxidized and leached chalcocite blanket. In detail considerable interfingering takes place, as one would expect, because of the irregularities

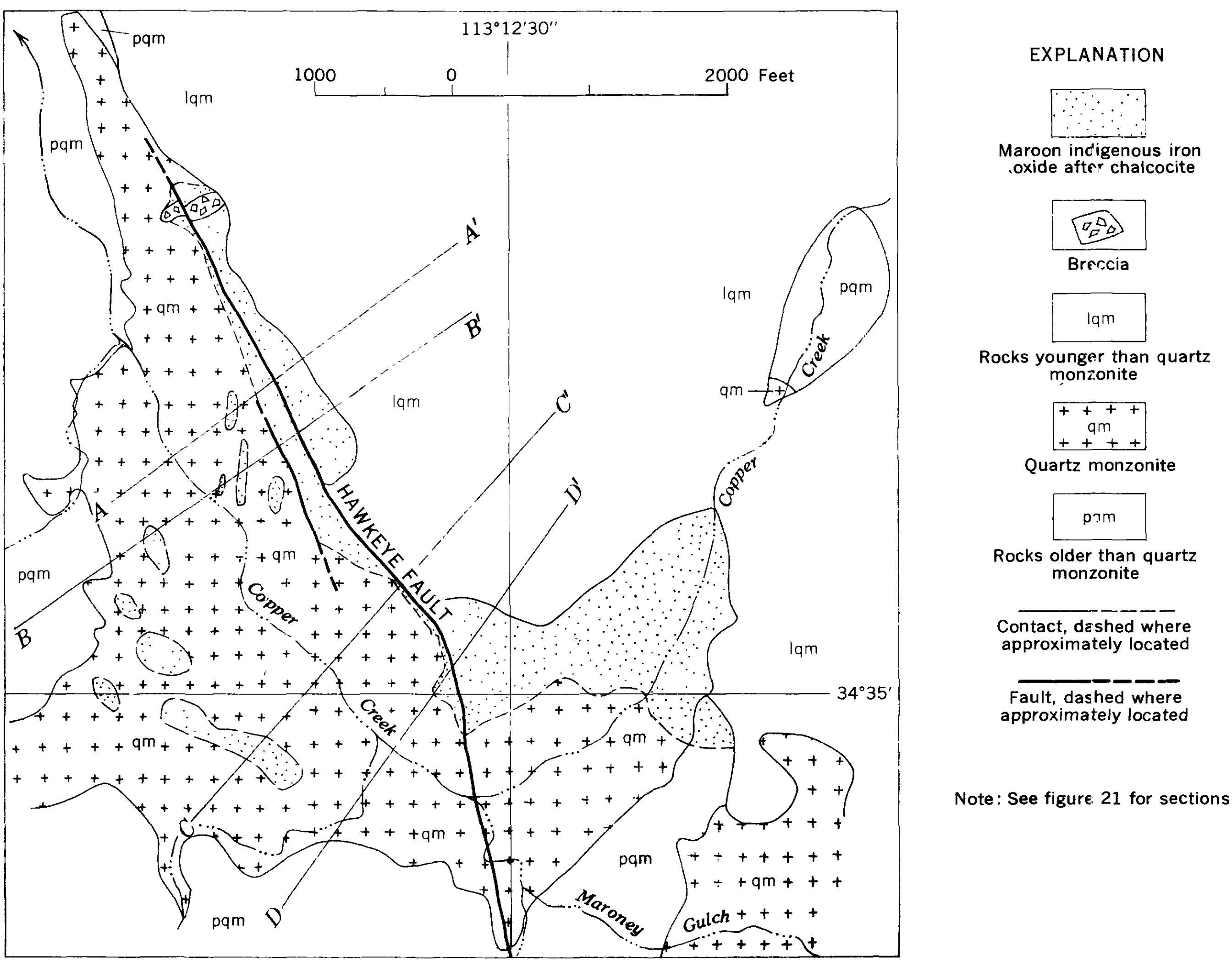


FIGURE 20.—Map showing distribution of iron oxide after chalcocite, Bagdad area, Arizona.

of the base of the chalcocite zone as exposed in the mine, but in many places the boundary could be located within 20 to 30 feet, accurate enough for the scale of the map. After this map was prepared, the boundary of the chalcocite blanket and the zone of primary sulfides was revealed on two sides of the glory hole, and this boundary coincides closely with the boundary shown in figure 20 as determined by a surface study.

The writer of one of the private geological reports in the files of the Bagdad Copper Corp. suggested that the Hawkeye fault was only of minor importance in the displacement of the chalcocite zone, and that between Copper Creek and the Hawkeye fault (see fig. 20) the oxidized part of the chalcocite zone is exposed. This area was investigated carefully; the type of iron oxide in the leached rock was plotted, and the indigenous relief iron oxide, characteristic of the oxidization of chalcocite, was found to be limited in its distribution west of the fault. It occurs in a narrow zone, seldom as much as 300 feet wide, bordering the fault. But elsewhere to the west, indigenous relief iron oxide after chalcocite is sporadic in its distribution, in marked contrast to the area east of the fault, particularly over the main ore body. Most of these patches can be related to the slips along which appreciable malachite, azurite, and chrysocolla have been deposited; some are rich enough to be mined to shallow depths for shipping ore. Not all these patches have been shown on figure 20, for many are too narrow and discontinuous to plot on a map of this scale, but the larger areas are shown to illustrate their sporadic distribution. Over much of this area west of the Hawkeye fault, the iron oxide is largely transported oxide or is contiguous to the cavities, and only a little indigenous iron oxide is present. All the iron oxide gives a yellow or yellowish-brown streak, indicating that little or no chalcocite was present and the oxidized sulfides were pyrite and chalcopyrite, a point verified by examination of exposures in some of the gulches and the prospect adits. Proof that the chalcocite zone is absent on the west side of the fault is shown by assays from churn-drill holes that were drilled after the submission of the private report mentioned; these churn-drill holes are shown in part on section *C–C′*, figure 21. It should be emphasized that the outcrop studies pointed to this same conclusion, which was made before the study of the churn-drill records.

The absence of the chalcocite zone west of the Hawkeye fault is explained by the nature of the fault itself, for other evidence proves that the east side is the dropped block, and it is logical to conclude that the chalcocite zone has been eroded from the footwall or the block west of the Hawkeye fault, as shown on figure 21. The origin of the sporadic patches of chalcocite

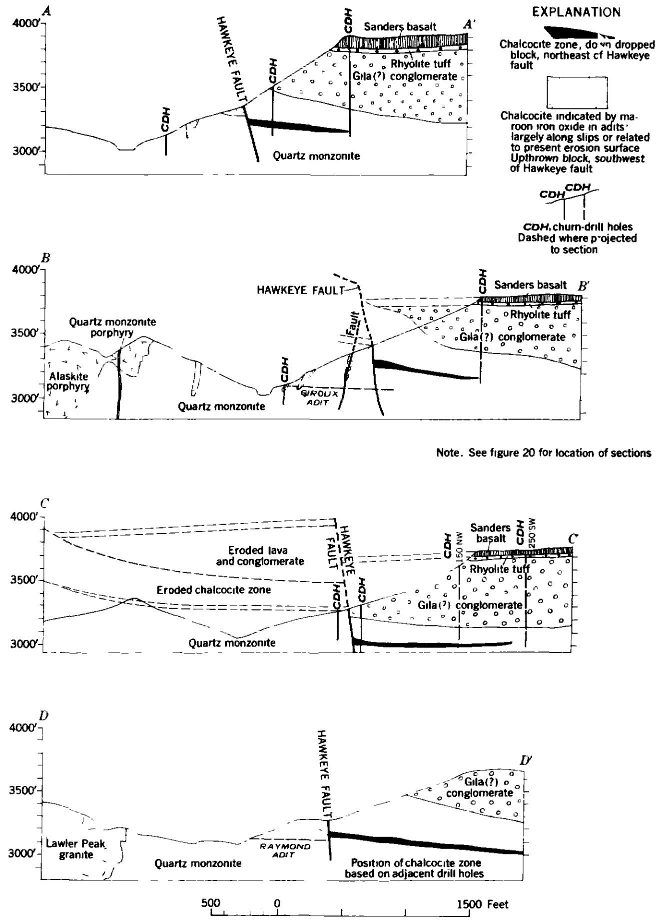


FIGURE 21.—Sections through chalcocite zone northwest of Bagdad mine, Bagdad, Ariz.

to the west presents a problem not easily answered. One explanation is that these local concentrations were roots of the original chalcocite zone, the slips allowing deeper penetration of the copper-bearing solutions. In contrast to this explanation, these faults, in part at least, may be younger than the original chalcocite enrichment, and may be related to the Hawkeye fault, which is definitely post-Gila(?) in age. The erosion of the chalcocite zone may have provided some copper-bearing solutions, for pyrite residues are common in the best chalcocite ore in the Bagdad mine, and oxidation of this pyrite would provide the ferric sulfate necessary to attack the chalcocite and form cupric sulfate. Solutions of the latter, upon downward migration, would deposit chalcocite.

The possibility of cyclic enrichment, as suggested by Ransome (1919, p. 172), exists, and the chalcocite blanket may have had a protecting influence, owing to its slow rate of oxidation. After the chalcocite blanket was eroded, the underlying protore would again be exposed to the action of air and the downward migration of rain water, and a second cycle of enrichment would begin. If this has happened west of the

Hawkeye fault, little or no copper from the pre-Gila(?) chalcocite blanket would remain. And the suggestion that a second cycle is beginning in the area between Copper Creek and the Hawkeye fault has supporting evidence, for some chalcocite coatings are found on chalcopyrite from exposures near the surface. The amount of chalcocite is insufficient to form red indigenous relief iron oxide but sufficient to raise the grade of copper slightly. Yet in two of the prospect adits, the Giroux and the Raymond (fig. 21), these chalcocite coatings are found only near the portal or along slips where permeability was greater. This would suggest a coincidence of slight enrichment with the present erosion surface, which implies that a new cycle of enrichment is beginning, but erosion has been too rapid for the formation of appreciable amounts of supergene chalcocite ore.

An area southwest of Copper Creek (cut by section *C–C′*, fig. 21) exposes red indigenous relief iron oxide that cannot be related to any slips as it is uniformly distributed through the quartz monzonite at the top of a ridge. This ridge lies to the southwest of a canyon filled with Gila(?) conglomerate (fig. 20) and is the basis for the assumption that this pre-Gila(?) canyon, trending northeast, had its base above the present ridge and that the indigenous iron oxide represents the leached part of the chalcocite zone which has been eroded elsewhere (fig. 21, *C–C′*).

It was hoped that some information concerning the distribution and former presence of molybdenite could be obtained from observations of the outcrops, but our studies were futile on this point. The only positive information we can supply is that molybdenite is not attacked by the enriching solutions, for it is present in the chalcocite blanket and shows no signs of alteration or attack. At the bottom of one of the gulches east of Copper Creek, molybdenite was found in association with pyrite but on the higher walls of the gulch, the pyrite was oxidized to iron oxide although the associated molybdenite was unweathered, indicating that it is slower to oxidize than pyrite. No ferrimolybdite was found in the capping, and an examination of the leached outcrops with an ultra-violet lamp failed to reveal powellite, a common oxidation product of molybdenite (Vanderwilt, 1942, p. 28).

ZONING OF COPPER

The grade of copper in the protore or primary-sulfide zone will be of economic importance when lower grade ore can be mined. In the exploratory drilling for the chalcocite blanket, most of the drilling was stopped when the drill holes reached depths from 20 to 50 feet below the base of the appreciably enriched ore. Therefore little direct assay information is available about the grade of the protore beneath the thicker and higher grade chalcocite ore. One method of estimating the grade of the protore is to plot the copper content obtained from all churn-drill records against the vertical distance below the base of the chalcocite blanket. It is seen that a flattening of the resulting curve takes place at increased depth, leveling off at about 0.5 percent copper, and this figure could be used as the average grade of the protore. However, some objections can be raised to this method, namely: (1) that if the chalcocite blanket is thin or of low grade, the churn-drill hole will be drilled to greater depths in the hope of finding higher grade copper ore; (2) that if a thick high-grade ore zone is proved, on the other hand, no incentive remains for further deep drilling. Plotting of grade of copper ore against depth below the base of the chalcocite blanket yields adequate date for the poorer grade areas, but not for protore under the higher grade areas.

A study of the isopach map (fig. 19) shows that the chalcocite blanket is highly irregular in thickness. Without revealing all the details of the distribution of grade, it can be noted that the grade of the chalcocite ore is also erratic, 160 vertical feet of chalcocite ore in one place in the mine may have a grade of 1.70 percent copper, whereas elsewhere in the mine 160 vertical feet of ore may have a grade of 2.55 percent copper. A study of the churn-drill records reveals that the grade of copper decreases in certain directions away from the mined areas. In order to obtain a picture of the distribution of copper, the total grade of copper of both oxide and sulfide ore to a depth of 500 feet below the bedrock surface was determined from the churn-drill and diamond-drill records. For some of the shallow holes the grade was estimated for the lower part by interpolation from records of assays from adjacent drill holes or underground workings. However, the assays from the drill holes actually determined the overall grade, for in several shallow holes several reasonable values for the grade were used in the interpolation for the lower part, but the overall grade determined was always within the limits of the unit selected for separation. Figure 22 shows the result of plotting these grades, and it illustrates the zoning of the ore body, and that the highest grade ore is found largely in the ore body now being mined (west ore body). Northeast and northwest control of the deposition of the ore is also suggested, which agrees with the structural interpretation.

If it is assumed that little lateral migration of copper has taken place during the enrichment, the amount of copper present as oxidized copper minerals in the leached zone, as chalcocite in the enriched zone, and as chalcopyrite in the protore might give a rough estimate of the original grade of the copper in the protore. If

FIGURE 22.—Density of copper in Bagdad mine area, Bagdad, Ariz.

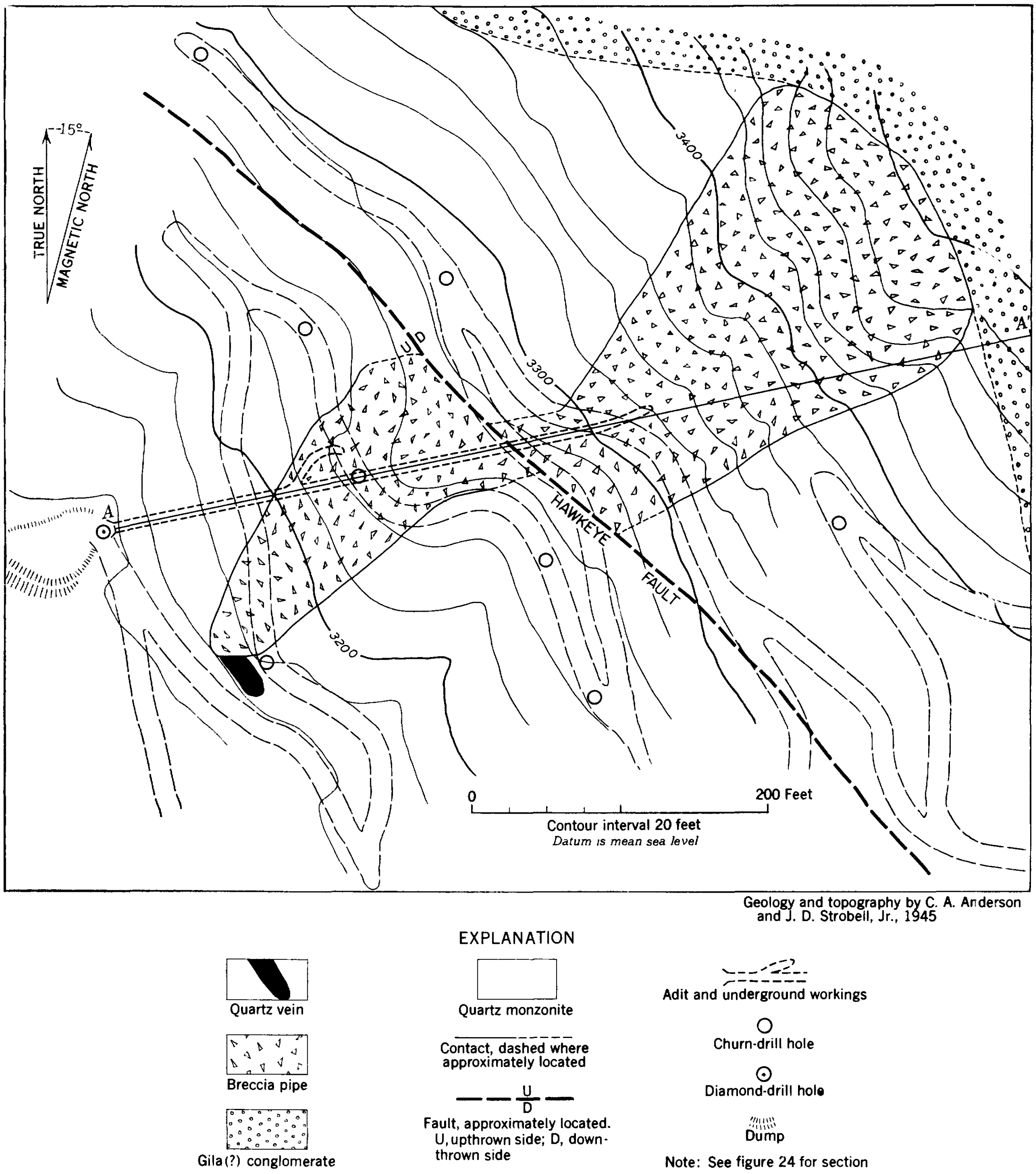


FIGURE 23.—Map of Black Mesa breccia pipe, Bagdad, Ariz.

this assumption is correct, another assumption must be made; that the copper added to the protore to form the chalcocite blanket has been derived from the leached zone now remaining. No evidence can be found to support this argument and, locally at least, much of the leached zone has been eroded. Lateral migration of the copper-bearing supergene solutions cannot be denied, and the conclusion that the best grade and thickest sections of chalcocite ore are present where many faults increase permeability, postulates lateral migration. Whether or not a higher grade protore is present beneath the areas of better grade chalcocite ore can only be ascertained through additional exploration of this protore. The available assay data suggest that this grade is between 0.4 and 0.6 percent copper. Sufficient data have been collected to conclude that the grade in the protore decreases to less than 0.4 percent copper beyond the areas of higher-grade chalcocite ore.

Figure 22 serves another useful purpose in that it shows graphically how few drill holes there are in areas that should be explored for additional chalcocite ore. Additional drilling will provide other welcome data for changing the details of the boundaries of the zones as now drawn, but sufficient information is available now to show in a general way that zoning of copper ore, both oxide and sulfide, is an important feature of the Bagdad deposit.

MINERALIZED BRECCIA PIPES

The breccia pipe that has been the most intensely mineralized and that has been prospected most extensively is the Black Mesa pipe (fig. 23), on the east side of Copper Creek, less than a mile to the north of the Bagdad mine (fig. 22). The fragments are largely of quartz monzonite, though some may be of diorite porphyry, but the fragments are so sericitized and silicified that original textures cannot be recognized with certainty in most specimens. The fragments range from 1 inch to 1 foot across and they are cemented by irregular vuggy quartz veins as much as 2 inches wide.

The sulfide minerals are confined largely to the vuggy quartz veins; and pyrite and chalcopyrite crystals nest in the vugs, and smaller grains are embedded in the quartz. Fine flaky molybdenite crystals are distributed sporadically through the breccia, appearing mostly at the margins of the cementing quartz veins, but a few flakes appear in the vugs. Small veinlets of quartz cut the altered quartz monzonite fragments and carry the three sulfides in variable distribution.

The sulfide mineralization is somewhat sporadic; the largest and most abundant chalcopyrite crystals appear at the western margin of the Black Mesa pipe where it is intersected by the adit (fig. 24). Assays indicate a copper content that locally is as much as 4 percent. Toward the end of the adit the grade decreases appreciably owing largely to the disappearance of the large chalcopyrite crystals of the vugs. Pyrite occurs throughout the adit. In the adit level, the chalcopyrite is largely coated with chalcocite, particularly near the western margin of the pipe, and the record of the one churn-drill hole in the pipe (fig. 24) indicates that a 95-foot leached zone is present and grades downward into a 45-foot enriched zone. The last 180 feet of the drill hole is in low-grade primary sulfides. A diamond-drill hole drilled obliquely from the surface failed to intersect any high-grade ore (fig. 24). The outcrop shows no sulfide minerals and the only carbonate of copper appears where the Hawkeye fault cuts through the pipe. Some transported iron oxide is common as well as indigenous iron oxide. The latter includes some maroon

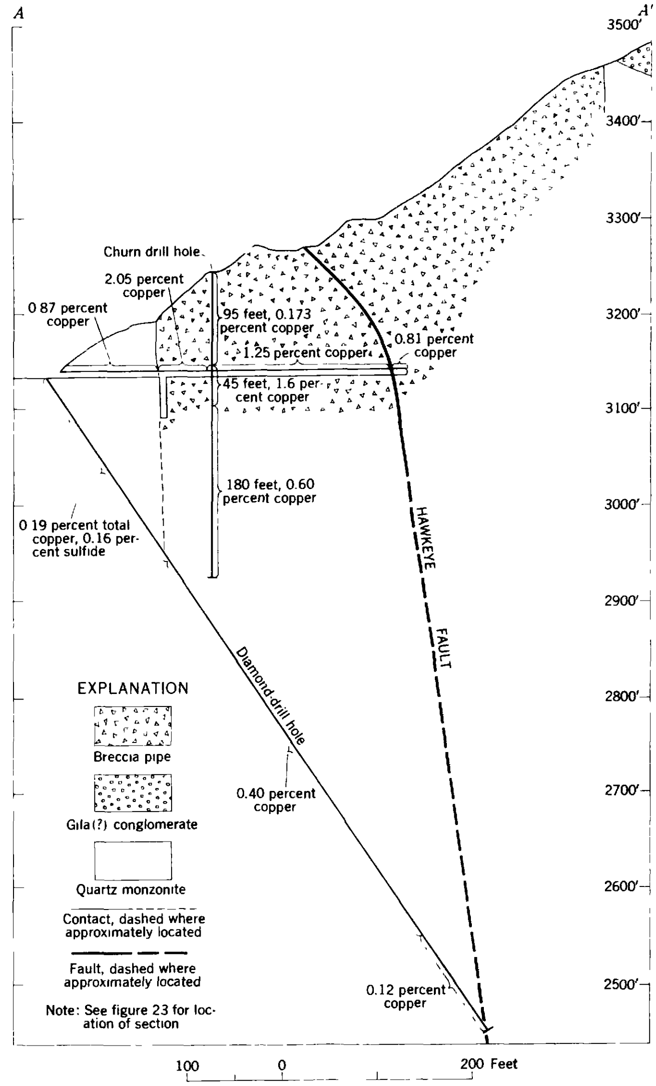


FIGURE 24.—Section through Black Mesa breccia pipe, Bagdad, Ariz.

fluffy "relief" iron oxide (fig. 20), which indicates the leaching of chalcocite, and a boxwork of reddish-brown iron-stained quartz septa, which suggests the leaching of chalcopyrite.

Although some primary copper ore is present, the available evidence indicates that chalcocite enrichment is responsible for the better grade copper in the assays of samples that have been obtained on the adit level and that the grade decreases at depth. Whether or not this chalcocite enrichment is related to the pre-Gila(?) or to the present erosion surface cannot be determined with assurance, but the fact that elsewhere to the southeast the Hawkeye fault marks the western boundary of the pre-Gila(?) chalcocite zone implies strongly that the enrichment in the Black Mesa pipe on the west side of the fault is related to the present erosion surface.

The breccia is heavily coated with chalcanthite along the adit walls for the first 100 feet. A little antlerite was also observed. This indicates that leaching is taking place at the present time. The water table is at the bottom of the winze, 40 feet below the adit level; this is about the margin between the zones of high- and low-grade copper content in the neighboring churn-drill hole (fig. 24). This fact might be offered as evidence of deposition of chalcocite above the water table.

Commercial-grade ore bodies have been found in breccia pipes that have only feeble surface expression, such as the Colorado pipe at Cananea in Sonora, Mexico (Perry, 1933), and the possibility always exists that a better mineralized rock can be found at depth. Although this possibility has not been ruled out completely at the Black Mesa pipe, the exploratory work done so far is not encouraging. Perhaps a better prospecting target would be a zone with enriched chalcocite in the part of the pipe east of the Hawkeye fault.

A small mass of brecciated quartz monzonite is present north of the west ore body of the Bagdad mine and near the contact of the Gila(?) conglomerate. (An idea of its general location can be obtained from fig. 22.) This breccia mass is 30 to 60 feet wide and 370 feet long and has a trend of N. 80° E. The quartz monzonite fragments are cemented and veined by quartz. This breccia may have been formed by intersecting faults before mineralization or it may be a breccia pipe. Little is known of the mineralization, for there are no churn-drill holes in the breccia.

Gossan outcrops indicate mineralized breccia in some of the other pipes west and south of the Black Mesa pipe, but these gossans are usually limited in area and the few prospect pits are all in the oxidized zone. Two pipes, one, the farthest north along Niagara Creek and the other along the headwaters of Alum Creek, have been prospected by adits. Both adits show considerable pyrite occurring as cubes in the cementing quartz or as disseminated grains in the fragments. Some of the pyrite has a thin coating of chalcocite, but chalcopyrite is rare, being almost completely replaced by chalcocite. Walls of both adits have sporadic thin coats of chalcanthite.

MASSIVE-SULFIDE REPLACEMENT DEPOSITS

HYPOGENE MINERALIZATION

The Old Dick and Copper King mines provide the only known examples of massive-sulfide replacement deposits in the Bagdad area. The sulfides have replaced rocks of the Bridle formation in the Copper King mine near an intrusive mass of King Peak rhyolite and in the Old Dick mine near a similar mass of Dick rhyolite.

At the Copper King mine the ore is localized in a unit of tuffaceous sedimentary rock near massive lavas of the Bridle formation. The ore appears as massive-sulfide lenses from 2 to 10 feet wide, and from 10 to 120 feet long, and as much as 100 feet deep, and lies in a broad northeast-trending zone of minor faults. In detail, the ore is localized along interlacing small faults and along rolls in the bedding of the tuffaceous sedimentary rocks which strike northeast, and are overturned and dip 45°–55° NW. The ore zone is essentially parallel to the bedding and zone of minor faults.

At the Old Dick mine the ore zone is west of the Dick rhyolite and confined to foliated lava flows of the Bridle formation. The ore bodies are massive-sulfide lenses that strike north, rake to the south at an angle of 35°, and range in dip from 45° to 90° in a westerly direction. The maximum width of any lens is about 35 feet, thinning toward the ends, and the maximum length is about 300 feet. The available evidence suggests that a fault zone along the western margin of the Dick rhyolite was an important control in the localization of the massive sulfide lenses; in addition, the foliation which dips as low as 45° has been an important control.

Alteration of the Bridle formation is more widespread and intense at the Old Dick mine than at the Copper King mine. The silicified and sericitized zone containing the sufides at the Old Dick mine lies along the contact of the intrusive Dick rhyolite, but wholly within the Bridle formation, and extends westward to intrusive diabase. The alteration took place after the intrusion of the diabase, for this rock is locally sericitized and silicified. At the Copper King mine, the bleached sericitized and silicified zone in the Bridle formation is of limited width, ranging only from several inches to 3 feet along the solution channels.

The Copper King ore consists of massive granular brown resinous sphalerite in association with smaller quantities of chalcopyrite, pyrite, and galena. The sequence of mineralization is difficult to determine precisely in these massive lenses, but the chalcopyrite and galena probably were deposited late in the sequence along with pyrite, but earlier some pyrite was deposited simultaneously with sphalerite. Polished surfaces of the massive sphalerite show only a little scattered chalcopyrite in irregular to rounded grains, and pyrite crystals are sporadically distributed. Some quartz was introduced during metallization and is associated with the sulfides, rarely appearing as minute crystals in vugs. Gold and silver are important recoverable metals. It is presumed that the silver is largely associated with the galena. Along the margins and ends of the lenses of massive sulfides, specular hematite with magnetite appears locally, and a large mass crops out at the surface on the footwall side of the ore zone. Some quartz is present also. Polished-surface studies indicate that the bulk of the iron oxide is platy hematite intergrown with a small amount of magnetite, which is large enough, however, to deflect the compass needle.

The spatial relations of the specular hematite-magnetite masses suggest that they were deposited early.

The massive-sulfide ore lenses at the Old Dick mine consist of resinous yellowish-brown and black sphalerite, the latter variety probably contains considerable iron (marmatite). Pyrite is concentrated in irregularly spaced narrow bands one-sixteenth to one-fourth of an inch in width that give the sufides a linear structure. Even where banding is dominant, crystals of pyrite, some quite large and apparently corroded, are disseminated throughout the massive sphalerite and the pyritic bands are by no means monomineralic. Chalcopyrite occurs in minute stringers and also as wide layers that cut the massive sphalerite or follow the edge of pyrite bands. Polished surfaces reveal minute grains of chalcopyrite uniformly distributed throughout the sphalerite; some of the chalcopyrite grains are veinlike, which suggests that the chalcopyrite is replacing the sphalerite. Galena forms local pods in the ore lenses, some of which are large enough for separation in mining. Conspicuous steel-gray euhedral arsenopyrite crystals as much as one-fourth of an inch in length are disseminated through the massive sulfides. These crystals are a cobaltian variety of arsenopyrite. Minute veinlets of sphalerite cut the broken crystals of arsenopyrite and show that the latter mineral was deposited early in the sequence. Some gold and silver are present.

The replacement origin of the sulfides at the Old Dick and Copper King mines cannot be proved conclusively, but the lenses of massive sulfide localized along fault zones and foliation planes of the enclosing rocks have none of the characters of filled veins. Preservation of the foliated and amgdaloidal structures of lava flows of the Bridle formation in the silicified and sericitized altered facies of this formation at the Old Dick mine is indicative of replacement origin. Some of the banding in the sulfides is parallel to the foliation of the schist, but in contrast, some of the banding in the Old Dick sulfide lenses dips east, opposite to the regional dip of the foliation. Possibly some banding was formed by replacement along lines of fracture. Fragments of schist in the Old Dick ore are completely enclosed by massive sulfide, and banding in the adjacent ore is parallel to the margins of the schist inclusions. This feature might suggest that the more permeable fractured rock was most easily replaced, leaving larger fragments as horses in the ore. It must be admitted that the replacement origin of the massive sulfide lenses is based on the complete lack of evidence of vein filling.

SUPERGENE MINERALIZATION

Supergene mineralization, including oxidation, has been an important process at both sulfide replacement deposits. At the Old Dick mine, chalcocite and covellite occur as coatings, most notably on the sphalerite, but also on the pyrite and chalcopyrite; neither is present on the cobaltian arsenopyrite. The distribution is not uniform, but in the lenses where these two copper sulfides are abundant, the copper content is two to three times that of the primary sulfides. The oxidation of the copper minerals at or near the surface formed the only ore that was shipped before 1945. This ore was mined to a depth of 30 feet. Malachite and azurite are the chief oxidized copper minerals but locally cuprite is important. The shipping ore averaged around 10 percent copper, which suggests that a considerable enrichment in copper took place in the upper 30 feet. Originally the enriched ore probably was supergene in the form of covellite and chalcocite and later oxidation of these minerals formed the carbonates and oxide. An oxidized zinc mineral is present as indicated by 3- to 4-percent zinc content in the ore, but whether this mineral is hemimorphite or smithsonite or whether both minerals are present could not be determined.

At the Copper King mine, a richer mineral suite is present in the oxidized zone, owing to the more abundant supergene lead and zinc minerals as well as those of copper. Chyrsocolla, malachite, azurite, and native copper are in the oxidized zone, and beneath it chalcocite and covellite partly replace sphalerite and chalcopyrite, locally forming masses as rich as 40 percent in copper. Some chalcanthite appears on the walls of the drifts. Earthy smithsonite and crystals of hemimorphite are the two common forms of zinc-bearing minerals in the oxidized zone and are associated with some anglesite and cerussite formed from the galena. Appreciable quantities of cellular to fluffy iron oxide, ranging in color from red to yellow, occur in the oxidized zone, either adjacent to or above the massive sulfides. Gypsum crystals as much as 2 inches long have been found in the oxidized zone. Conichalcite, a copper-bearing arsenate is locally present, indicating that some arsenopyrite is probably present in the sulfides, but none was detected in our study. Goslarite, the efflorescent deposit of zinc sulfate, coats the walls of the drifts in the upper levels.

The oxidized zone at the Copper King is rich enough in zinc and copper that shipping ore of both metals was mined throughout the period of World War II.

GOLD-SILVER-COPPER-LEAD-ZINC VEINS

A number of simple fissure quartz veins contain variable amounts of pyrite, sphalerite, galena, chalcopyrite, silver, and gold. The Hillside vein is by far the most important economically and has yielded an impressive amount of gold, silver, lead, and zinc. Other veins that have been mined are on the Cowboy, Mountain

Spring, Comstock-Dexter, Stukey, Goodenough, and Vidano claims. Zinc has not been recovered from any of these last named properties, as the ore has been shipped direct to the smelters for the recovery of gold, silver, lead, and copper. Several prospect pits and shafts have been sunk on some of the many outcrops of quartz veins in which limonite, malachite, azurite, and cerussite all appear and indicate a similar mineralogy for the primary-sulfides, though these pits rarely reach the sulfide zone.

The Hillside vein coincides with the Hillside fault, a major fault in the north-central part of the Bagdad area, and the Mountain Spring vein coincides with the Mountain Spring fault, an equally important fault in the south-central part of the area. The other veins are located along minor fractures with no measurable displacements. Postmineral faulting has been very important at the Hillside mine; as a result gaps in and overlaps of the ore are present along the vein, and also important gouge zones that have presented problems in mining.

These veins range in width from less than 1 foot to 4 feet, and can be traced for distances from a few feet to as much as a mile; the longer veins include several discontinuous veins cropping out in strike extension. The Hillside vein has been explored along the strike for a distance of 2,700 feet and has been explored down the dip for more than 900 feet.

HYPOGENE MINERALIZATION

The zone of altered wall-rock adjacent to the veins usually ranges in width from several inches to a foot; alteration is marked by introduction of some quartz and by formation of sericite.

In the Hillside vein at least three periods of quartz-sulfide deposition have been recognized from the banding and local comb structure. Some intramineralization faulting is indicated by microbrecciation of the sulfides and cementation by later quartz. Pyrite and arsenopyrite generally are present in the massive vein quartz, in places forming irregular bunches. Galena also appears as bunches in the quartz, and in separate crystals associated with pyrite. Sphalerite forms aggregates of yellow to light-brown translucent crystals, both in the more massive sulfide bunches, and in the quartz-vein material. Polished surfaces reveal minute inclusions of chalcopyrite in the sphalerite, arranged parallel to the cleavage. Elsewhere, chalcopyrite occurs sparingly as blebs. Argentiferous tetrahedrite (freibergite) was found coating the other sulfides and in vuggy quartz crystals. Locally argentite is present in the vein as minute needles attached to vuggy quartz crystals and also as small stringers near the top of the sulfide zone, so it may be in part or entirely of supergene origin. Part of the silver occurs in the argentite and part in the tetrahedrite, but most of the silver is probably associated with galena, for in milling most of the silver appeared in the lead concentrate. A little silver present in the zinc concentrate suggests that possibly in part it is associated with sphalerite. The gold is finely divided and none was detected under the microscope. Probably it is largely associated with the pyrite and arsenopyrite, for when these minerals were depressed in the concentrator, considerable gold was lost in the tailings (H. L. Williams, Jr., oral communication).

A little pinkish-gray manganosiderite was found in veinlets spatially related to the tetrahedrite, and both were probably introduced late. The general sequence at the Hillside vein is shown graphically in figure 25.

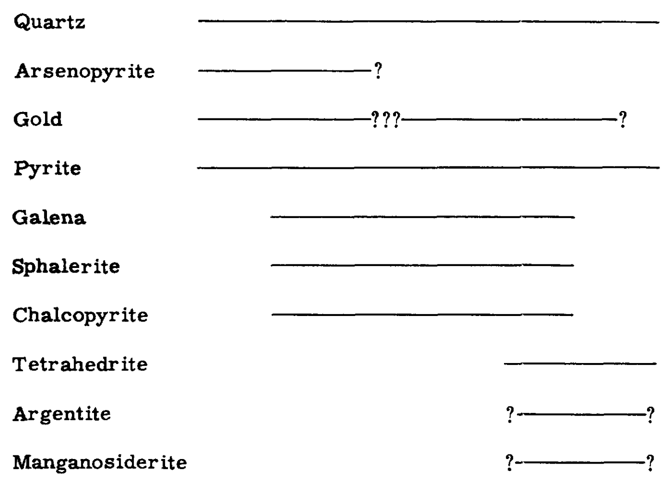


FIGURE 25.—General sequence of mineralization at the Hillside vein.

Complete assays were available only for 3 levels in the Hillside mine, the 700-, 800-, and 900-foot levels. Contouring the concentration of gold and silver in the ore of these levels suggested that a zone of higher grade gold-silver ore had a rake of 55° to the north. Cross sections revealed that changes in the dip of the vein had some control on the width of the vein, for in areas where the vein is convex to the west the vein is wider and the content of gold and silver is of average grade or better.

The Comstock-Dexter vein is apparently a part of the south extension of the Hillside vein and is similar to the Hillside vein in mineralogy and is also broken by postmineral faults. The ratio of gold to silver in the Comstock-Dexter ore is 1 to 15, whereas in the Hillside ore it is 1 to 34. However, future mining of the Comstock-Dexter vein might yield ore of a different ratio.

The Stukey, Cowboy, Mountain Spring, Vidano, and Goodenough veins have all yielded small though variable amounts of gold, silver, copper, and lead. These veins consist of quartz gangue with pyrite, galena, and sphalerite, and subordinate chalcopyrite. Arsenopyrite is the chief sulfide mineral in the Kyeke vein, and is associated with a little pyrite in quartz vein material; other sulfides are absent.

SUPERGENE MINERALIZATION

Oxidation of the upper part of the Hillside vein has caused some enrichment and has formed a large suite of supergene minerals. Because this vein has been most extensively developed, more workings are available for observation than for the other veins of the district. Where the outcrop has not been mined, the vein is largely crushed quartz heavily stained with limonite. Gold has been unaffected by oxidation, except for possible local enrichment and its liberation from the gold-bearing sulfides. Some parts of the vein have been enriched appreciably in native silver and cerargyrite, particularly those parts along north-dipping cross faults, where it is reported that large bunches of wire silver and cerargyrite were found. Cerussite is the most important oxidized lead mineral, but some coatings of anglesite were found on galena. Zinc content is low in the oxidized zone (H. L. Williams, Jr., oral communication), but some smithsonite and hemimorphite are present. Goslarite is common as coatings 1 inch thick on some of the walls of the upper levels. Supergene chalcocite and covellite were found as thin coatings along fractures in the sphalerite. Malachite and chalcanthite are common, the latter being abundant locally. Pharmacosiderite appears locally as minor coatings. Efflorescent deposits of gypsum also line some of the walls of the upper drift level, and in one place north of the shaft on the 300-foot level, brilliant, yellow uranium-bearing crystals (schroeckingerite, bayleyite, swartzite, and andersonite) form a coating one-eighth of an inch thick mixed with gypsum. It might be noted that an assay of 2.3 percent U_3O_8 is recorded on one of the company assay plans of the 700-foot level directly down the dip from the uranium minerals occurrence on the 300-foot level, but the 700-foot level was under water in 1945 and the source material could not be observed. Dripstone deposits of hisingerite appear in one of the drifts beneath filled stopes.

The bottom of the oxidized zone is irregular, for locally in the less fractured vein quartz, sulfides can be found a few feet below the surface. Generally, oxidation has taken place down to the 300-foot level, which is 60 to 250 feet below the surface, but sulfides are in excess below this level, and little or no supergene minerals appear below the 400-foot level (40 feet below the 300-foot level). The 400-foot level is about at the position of the water table, which coincides with the bed of Boulder Creek.

The other veins are marked at the surface by limonite of variable quantity mixed with some cerussite and anglesite. Malachite, chrysocolla, and azurite may or may not be present. Hemimorphite and wulfenite were noted at the Mountain Spring mine, and wulfenite and pyromorphite were found in a prospect pit near Bevering Gulch. Limonite only is found in the oxidized portion of the Kyeke vein.

TUNGSTEN VEINS

Along Boulder Creek in the northeast corner of the Bagdad area, wolframite-bearing veins appear in the muscovite-granite facies of the Lawler Peak granite. The wolframite crystals, as much as one-quarter of an inch long, occur in closely spaced, nearly vertical, parallel quartz veins as much as 1 inch and, rarely, 2 inches wide. South of Boulder Creek they form a zone nearly 12 feet wide and strike northwest and have a continuity of 200 or 300 feet. On the north side of the creek, however, an easterly-trending zone of veinlets that is 10 to 50 feet wide crops out for a distance of more than 2,000 feet. Development of this easterly-trending zone of veinlets was being done at the Tungstona mine in 1952.

Beryl is an important accessory mineral in the quartz veins and locally is very abundant. Small amounts of scheelite occur in thin films and crusts on the surface exposures and it is reported that scheelite has been found in the underground workings of the Tungstona mine. Genetically the veins are the result of filling of fissures by late-stage emanations from the Lawler Peak granite magma.

AGE OF MINERALIZATION

The copper-lead-zinc-gold silver deposits appear to have a common origin, and some of these can definitely be proved to be younger than the quartz monzonite and related intrusive rocks. The period of mineralization has been tentatively assigned to the Cretaceous or early Tertiary. The evidence for this conclusion will be presented below.

Gilluly (1942) concluded from very convincing evidence that there is a direct genetic relationship of copper metallization to the host rock at Ajo, Ariz. The changes in the quartz monzonite at Bagdad that include the albitization of the more calcic plagioclase, introduction of orthoclase, and formation of leafy biotite can be presented as evidence of hydrothermal activity probably related to intrusion of the quartz monzonite magma. No other igneous bodies are exposed that might be sources of hydrothermal solutions. It is evident that the visible part of the stock had solidified before alteration began, as indicated by the intrusion of aplitic dikes and by the presence of fractures that formed channels for the introduction of the hydrothermal solutions. The intimate association of the sulfides pyrite and chalcopyrite with the other hydrothermal minerals is proof enough that the metallization of the quartz monzonite stock was done by the hydro thermal solutions rising from an underlying magmatic reservoir. As to the time of metallization (and alteration) in relation to the time of intrusion of the satellite dikes of diorite porphyry and quartz monzonite porphyry, no direct evidence is available, because none of these dikes cut the metallized quartz monzonite in the Bagdad mine where direct observation can be made. In the southwestern exposures of the quartz monzonite west of the confluence of Mineral and Copper Creeks local intense alteration of the several quartz monzonite porphyry dikes suggests at least part of the hydrothermal activity occurred after intrusion of the dikes of quartz monzonite porphyry.

South of the Bagdad mine, particularly in the region of the Stukey mine, quartz veins bearing galena, sphalerite, and chalcopyrite cut dikes of quartz monzonite porphyry. Locally these veins parallel the dikes, crossing from one margin to the other, which suggests that the forces that opened the fractures occupied by the dikes continued to operate, forming new openings that are occupied by the veins.

In the Copper King mine a dike of diorite porphyry occurs in one of the massive-sulfide lenses in the northern part of the mine. Scholz made many observations on new faces of workings during the mining of this ore body and found conclusive evidence that the massive-sulfide lens is younger than the dike of diorite porphyry, and in places, the dike has been partly replaced by sulfide. Clear-cut veinlike bodies of massive sulfide penetrate the dike, locally grading into the dike. Pyrite bands in the ore are common adjacent to the dike and parallel the contact of the dike and sulfide lens. Similar relations are present where inclusions of the Bridle formation are left in the ore. Chilled selvages in the dike rock are absent adjacent to the massive-sulfide, whereas chilled selvages are common where the dikes intrude older rocks. This age relationship of the Copper King massive-sulfide to the diorite porphyry dike of Late Cretaceous(?) or early Tertiary(?) age is important because the massive-sulfide deposits in the Jerome area [3] are undoubtedly pre-Cambrian.

The breccia pipes, in part, are younger than the quartz monzonite, particularly the Black Mesa pipe, which shows the best sulfide mineralization; this would imply that the metallization in the breccia pipes is, generally related to solutions younger than the quartz monzonite. The Goodenough vein, cutting the rhyolite breccia plug on the west side of Boulder Creek, south of the Hillside mine, is similar to the Hillside vein, and is definitely younger than the rhyolite. On underground maps of the Hillside mine a "rhyolite" dike is shown on the north end of the 900-foot level, filled with water in 1945, and the Hillside vein is shown definitely cutting the dike. Quartz monzonite porphyry dikes crop out to the north of the Hillside mine, which implies that the "rhyolite" dike on the 900-foot level is, in reality, one of the quartz monzonite porphyry dikes dating the Hillside vein as younger than the quartz monzonite porphyry.

Some of this evidence may not be conclusive but the sum total of the evidence amounts to geologic proof that all the copper-lead-zinc mineralization is related and younger than the quartz monzonite. The deposition of the metals probably took place shortly after the intrusion of the quartz monzonite, for no other igneous bodies are present that could have been sources of the hydrothermal solutions bearing metals; this last fact would date the mineralization as Cretaceous or early Tertiary, if the tentative assignment of the Grayback Mountain rhyolite tuff to this interval of geologic time is accepted. Certainly this mineralization is younger than pre-Cambrian.

The Bagdad mineralization is similar to the Bingham Canyon mineralization, where copper ore was deposited in the stock and silver, lead, and zinc were deposited in the intruded rock. Butler (1920, p. 361) has suggested that highly heated solutions deposited the copper and that less highly heated solutions deposited the silver, lead, and zinc. On this assumption, the sphalerite and galena occurrences in the Bagdad mine may have been deposited later than most of the copper minerals.

The wolframite-bearing veins along Boulder Creek undoubtedly are associated with intrusion of the Lawler Peak granite for traces of wolframite are found in quartz-rich facies of the pegmatites and beryl is a common accessory mineral in many of the pegmatites. Furthermore no beryl or wolframite have been found in any of the other mineral deposits of the area. The wolframite mineralization is concluded to be pre-Cambrian. Several barren quartz veins 2–3 feet wide and striking east crop out south of Sanders Mesa, cutting the pre-Cambrian complex and one of these veins is cut by a dike of quartz monzonite porphyry. Southwest of the Copper King mine, small quartz-tourmaline veins are found, particularly in the alaskite. These nonmetallized veins may also be pre-Cambrian and related to the Lawler Peak granite or alaskite porphyry.

[3] Anderson, C. A., and Creasey, S. C.; Geology and ore deposits of the Jerome area, Yavapai County, Arizona: [In preparation.]

MINES AND PROSPECTS

BAGDAD MINE

The Bagdad copper mine, located along Copper Creek, is owned and operated by the Bagdad Copper Corp., which also owns the Black Mesa pipe, described on p. 75–76.

The Bagdad and Hawkeye claims were located on January 1, 1882, by W. J. Pace and J. M. Murphy. The Bagdad claim was the site of later intensive exploration for copper, and the name of this claim became attached to the area of activity along Copper Creek, eventually giving its name to the camp and to the operating company. In 1883 John Lawler located 5 additional claims along Copper Creek and bought the Bagdad and Hawkeye claims for $200; in 1886 he located the North Bagdad claim, and the 8 claims were patented in 1889 and 1890. These patented and several associated unpatented claims were known as the Lawler group of Copper Mines, and several transactions were recorded in the sale of fractions of claims, with the final ownership being held by John Lawler, W. E. Hazeltine, and Ed W. Wells. In 1906 the 8 patented and 12 unpatented claims were sold for $150,000 to the E. M. Bray Trust Co. In 1907 the Copper Creek Development Co., a corporation organized under the laws of the State of Arizona, obtained title to these claims. Several adits were driven as a part of the exploration program of this company. On July 1, 1909 the Copper Creek Development Co. was reorganized to include several mining properties in Nevada, and the new company was called the Arizona-Nevada Copper Co. A churn-drilling program was begun by this company. In 1911 a new company was organized, the Bagdad Copper Co., which was given ownership of the Arizona property, and an option with full control was given to the General Development Co. of New York (the Lewisohn interests), which drilled 11 churn-drill holes but relinquished the option in April 1913. In October 1913 the General Development Co. took another option for 5 years, but never exercised it. In March 1918 the Arizona Bagdad Copper Co. purchased the property. This company was reorganized and the name changed to the Bagdad Copper Corp., and in March 1927, the new organization took over the ownership and is now the owner and operator. By 1928, 128 churn-drill holes had been made.

Mining on a small scale started in 1929 and copper has been produced every year since, with the exception of the period 1931–34. Mining on a large scale began in 1943 after the Reconstruction Finance Corporation granted a $2,500,000 loan, which was used to construct a new mill of 2,500 tons daily capacity; to sink a new shaft; to prepare stopes for block caving; to bring water from Burro Creek, 7 miles to the west; and to bring in electric power from Parker Dam, 72 miles to the southwest. The new mill started operations on March 1, 1943, but labor shortages kept the ore supply to about half of mill capacity, and the situation was aggravated by overdrawing of the stopes and dilution of the ore by the leached capping (Anon. 1946). To increase production with the available labor supply and to avoid dilution from the leached capping in the mill feed, a glory hole with two transfer raises was begun in 1945; it was located at the southern margin of the west ore body where the unoxidized chalcocite ore appears near the surface (cross sections, figs. 13 and 14). The capping was stripped, the ore was blasted down from benches; power shovels then dumped it into the glory hole, or it was pushed in by bulldozers. The ore was collected in trains on the haulage level of the mine and hoisted up the main shaft. As a result of this method of combined block-caving and glory-hole mining by December 1945 the mill was operating at full capacity; 75 percent of the ore came from the glory hole and 25 percent from the stopes. In July 1946, a fourth transfer raise to the surface was completed, providing four ore passages from the surface to the haulage level, and by August 1946, 97 percent of the ore came from the enlarged glory hole. Conversion from the glory-hole method to open-pit method of mining occurred in 1947, when a primary crusher was installed in the open pit, and a 36-inch conveyor belt transferred broken ore from the open pit to the original crushing plant at the mill. All ore since that date has come from the enlarged open pit and underground mining was stopped. In 1950 another ball mill was added to the concentrator, and production gradually increased. Production for 1951 averaged 3,500 tons per day.

A premium of 5 cents per pound was paid for all copper produced during the period from the beginning of the expanded operations in 1943 to July 1, 1944; then an additional premium of 5 cents per pound of copper was granted until November 1, 1944. At this date the zero quota was changed so that the second premium of 5 cents per pound of copper was paid on all monthly production over 280,000 pounds (Anon., 1946). Premium payments stopped on July 1, 1947.

Table 7 shows the total production to the end of 1951 has been 125,991,174 pounds of copper. The ore carries only a trace of gold, and the total amount of gold recovered is only 85 ounces. The total amount of silver recovered is 292,969 ounces. As calculated on the basis of tonnages milled, the silver recovered from the ore averages about 0.02 ounce per ton. No information is available as to the form of the silver in the ore or as to the minerals with which it is closely associated. Molybdenite occurs sporadically through the

TABLE 7.—*Metals produced, Bagdad mine, 1929–51, in terms of recoverable metals*

[Compiled by the U. S. Bureau of Mines and published by permission of the owner. Ceiling prices used during periods of premium prices]

Year	Gold		Silver		Copper		Molybdenum		Total value
	Ounces	Value	Ounces	Value	Pounds	Value	Pounds	Value	
1929	4	$83	485	$259	277, 501	$48, 840			$49, 182
1930	1	21	741	285	245, 203	31, 876			32, 182
1931–34									
1935			361	259	179, 556	14, 903			15, 162
1936	1	35	1, 607	1, 245	884, 860	81, 407			82, 687
1937			2, 688	2, 079	1, 491, 278	180, 445			182, 524
1938			1, 095	708	713, 000	69, 874			70, 582
1939			431	293	292, 000	30, 368			30, 661
1940	11	385	2, 505	1, 781	1, 495, 000	168, 935			171, 101
1941	14	490	3, 340	2, 375	2, 229, 931	263, 132			265, 997
1942	6	210	1, 920	1, 365	1, 087, 000	130, 440			132, 015
1943	3	105	9, 725	6, 916	6, 959, 550	835, 146			842, 167
1944			14, 601	10, 383	9, 580, 000	1, 149, 600	73, 157		1, 159, 983
1945			14, 482	10, 298	8, 036, 000	964, 320	12, 669		974, 618
1946			20, 712	16, 735	11, 813, 600	1, 913, 803			1, 930, 538
1947			28, 700	25, 974	12, 900, 000	2, 709, 000			2, 734, 974
1948	45	1, 620	38, 363	34, 719	14, 059, 935	3, 051, 006			3, 087, 345
1949			37, 858	34, 261	15, 211, 760	2, 996, 717			3, 030, 978
1950			58, 300	52, 762	21, 055, 000	4, 379, 440			4, 432, 202
1951			55, 055	49, 825	17, 480, 000	4, 230, 160	149, 380	71, 620	4, 351, 605
Total	85	2, 949	292, 969	252, 522	125, 991, 174	23, 249, 412	235, 206	71, 620	23, 576, 503

mine and it was recovered from the copper concentrates for a year and a half, but owing to labor shortages and other factors, the molybdenite unit closed after 85,826 pounds of molybdenum were recovered. Table 7 shows that the recovery of molybdenite from the copper concentrate was resumed in the latter part of 1951, stimulated in part by the increased price of molybdenite concentrates. Excluding the molybdenum, the total value of recoverable metals at Bagdad through 1951 has been $23,504.883, a figure based on the ceiling prices of copper during the period in which premium prices were paid.

The now abandoned underground workings of the mine were entered through a 3-compartment shaft, 465 feet deep, having two hoisting compartments and a manway. The ore was hoisted in two 3-ton skips. The main haulage level is at a depth of 340 feet and has a 500-ton concrete storage pocket below the 340 shaft station. Until the beginning of the use of the gloryhole method, the mining was done by block caving and the ore body was laid out in blocks or stopes, 100 feet square, each block containing about 160,000 tons of ore. The undercut level was 30 feet above the haulage level and draw raises were spaced on 25-foot centers. Two haulage lines, 50 feet apart, each having 16 draw raises served each stope. In most of the blocks the walls were weakened by 3 boundary drifts, 30 feet apart vertically and driven around either 3 or 4 sides of the stopes. On the undercut level, drifts were driven diagonally across the tops of the draw raises, and as the pillars were blasted out, the vertical sections of the draw raises were belled out. The ore was drawn directly from the undercut level through the draw raises without passing through a grizzly, so that some chute blasting was necessary. In order to avoid the delays associated with chute blasting, the last 2 stopes prepared for underground mining has a grizzly level 15 feet above the haulage level, and the undercut level was 45 feet above the haulage level. Slushers were used in the grizzly level to bring the ore from the draw points to the transfer raises.

Huttl (1943) gave a complete description of the mill as it was operating in 1943, and a later paper (Anonymous, 1952) describes mill operations as of 1951. The copper sulfides, chalcocite and chalcopyrite, are concentrated by flotation methods, hauled by truck to Hillside, and shipped by rail to El Paso, Tex., for reduction. At first, all tailings were carried by a 7-inch (inside diameter) Transite pipe to a flat along Boulder Creek south of Bozarth Mesa, but as capacity of the site was being reached, an earth-filled dam was built across the mouth of Maroney Gulch and the tailings are dumped in the gulch. This site has the added advantage that some water can be returned for mill use.

The distribution and grade of the copper ore to 1945 were determined from the 128 churn-drill holes, about 20,000 feet of underground workings, and about 8,000 feet of underground diamond-drill holes. Many of the underground workings were inaccessible at that time, particularly around the mine owing to the caving of the ore body. Estimates on the reserves differed greatly in reports to the company and its predecessors, and, as shown by Butler and Wilson (1938c, p. 103), range from 5,000,000 to 35,000,000 tons, and the copper content ranges from 1.0 to 1.93 percent. In 1937, Whitaker and Schlereth estimated the reserves to be 6,000,000 tons of sulfide ore having an average of 1.47 percent copper (Butler and Wilson, 1938c, p. 103) and classified as ore only the mineralized rock that is indicated by fairly closely spaced churn-drill holes—the west ore body and the block to the northeast (fig. 22). A study of the sections through the ore body (figs. 17, 18, 19, 20) indicates that the marked irregularities in the thickness of the chalcocite zone demand close spacing of churn-drill holes or other exploratory openings before an accurate estimate can be made as to tonnage and grade. A considerable part of the original reserve of 6,000,000 tons as estimated by Whitaker and Schlereth was mined by 1946, and also some ore around the glory hole that was not included in their estimate. Considerable diamond drilling has been done since 1945 to block out ore for the open-pit operations, and Dickie and others (1953, p. 89) reported that the reserves total 30,000,000 tons of sulfide ore, averaging 0.754 percent total copper, and 30,000,000 tons of oxide copper ore, averaging 0.435 percent copper.

Based on the data from the many exploratory churn-drill holes and from several adits, appreciable tonnages of indicated and inferred ore are estimated to be present and are of sufficient copper content that continued mining can be predicted if prices for copper are favorable.

HILLSIDE MINE

The Hillside mine is a gold-silver-zinc-lead vein deposit located on Boulder Creek a little more than 3 miles north of Bagdad and east of Bozarth Mesa. The vein is a typical fissure vein, and, considering its narrow width, has remarkable continuity.

The Hillside mine started producing ore in 1887, after the location of the Hillside and Seven Stars claims by John Lawler and B. T. Riggs on March 11, 1887. Later that same spring, they located 4 adjacent claims and they were granted a patent on the 6 claims, February 6, 1892.

The Hillside mine was sold in June 1890, for $450,000 to H. H. Warner, who organized the Seven Stars Mining Co. During the next 2 years more than $100,000 worth of ore was mined and shipped. In 1892, the Seven Stars Mining Co. became delinquent in their payments, only $100,000 having been advanced on the purchase price, and after a long period of litigation, the title was restored to John Lawler and his partners in 1904.

From 1904 to 1914 lessees worked the Hillside mine, concentrating on development work so that 11,000 feet of workings had been driven when the mine was purchased in 1934 by the Hillside Mines, Inc. A concentrator with a capacity of 125 tons per day was built to mill the sulfide ores, and in 1937 additions to the flotation section of the mill provided for the separation of zinc and lead. In 1940 the Boulder Mining Co. took over from the Hillside Mines, Inc., on lease and option to purchase and operated the mine and mill until January 1942, when the mine closed because of financial difficulties.

The ownership reverted to the State of Arizona until it was purchased in 1944 by the East Vulture Mining Co. at a tax sale and transferred to the Hillside Mining and Milling Co., the present owners and operators. The mine was dewatered, the shaft rehabilitated, and the lower levels of the mine were opened in 1946 and 1947. From 1948 to 1950, ore from the lower levels was mined and milled, and production ranged from 500 to 1,800 tons per month. Mining stopped in 1951, owing in part to the difficulties in mining the heavy wet ore on the lower levels.

A 100-ton flotation mill was built on the property in 1946 to treat custom ore as well as ore from the Hillside mine. After the closing of the mine in 1951, the mill continued to operate as a custom mill. Water is stored in the Hillside mine for mill use in dry seasons when Boulder Creek is dry. In 1951, a 300-ton gravity concentrator unit was added to the mill to handle custom tungsten ore.

Total production to the end of 1951 (table 8) had a value of $3,541,440; about half of the value is in gold, and a quarter of the value in silver. Lead is an important recoverable metal, and zinc has become of considerable importance since 1937 when a unit was installed in the mill for its recovery. Table 8 shows that copper has been a relatively minor metal; only 398,813 pounds were recovered, having a value of $46,614.

More than 16,000 feet of underground workings have been driven along the vein at different levels; a composite map showing the underground workings as of 1942 and a longitudinal projection are shown on plate 6. The shaft connects with the 200-foot level at the surface and is 765 feet deep to the 1000-foot level. The vein was worked for 2,400 feet along the strike and stoped almost solidly above the 700-foot level for an average length of 2,000 feet. Cut-and-fill stoping methods were used in mining the ore on the lower levels, but shrinkage-stoping methods were used above the water level.

The main Hillside vein has a N. 10° W. strike at the south end of the mine and changes to a N. 25° E. strike at the north end. The dip is not uniform but averages between 75°–80° in a westerly direction. Faulting before and after mineralization has been important. The main vein and several branches occupy a zone of faults antedating the veins, and sufficient movement along the faults occurred after mineralization to form a 3-foot zone of gouge and fault breccia in which unbrecciated vein material is found as irregular veinlets. Branching veins appear on both sides of the main vein and those to the east in general dip west

TABLE 8.—*Metals produced, Hillside mine, 1887–1951, in terms of recoverable metals*

[Data for 1887–1900, from records furnished by H. R. Wood, Prescott, Ariz.; 1901–51 compiled by the U. S. Bureau of Mines and published with permission of the owner. Ceiling prices used during periods of premium prices]

Year	Gold		Silver		Copper		Lead		Zinc		Total value
	Ounces	Value	Ounces	Value	Pounds	Value	Pounds	Value	Pounds	Value	
1887	140		3,419				5,535				$4,449
1888	950		17,596				12,058				27,238
1889	1,229		57,221				7,313				64,078
1890	424		7,840				4,859				13,418
1891	426		15,633				2,401				17,423
1892	1,940		41,798				37,456				67,100
1893	707		14,076				15,104				23,031
1894	216		4,154				1,799				5,324
1895											
1896	858		12,915				2,668				21,490
1897	261		4,111				1,873				6,402
1898	159		4,744				11,917				5,183
1899	409		7,648				3,923				10,281
1900	105		1,794								2,502
Total 1887–1900	7,824		192,949				106,906				267,919
1901	75	$1,550	1,525	$915							2,465
1902	303	6,264	4,717	2,500							8,764
1903–5											
1906	271	5,602	3,726	2,496							8,098
1907–8											
1909	46	951	778	405			2,091	$90			1,446
1910	47	972	866	468	11	$1	2,349	103			1,544
1911	165	3,411	3,340	1,770	214	27	2,746	124			5,332
1912	404	8,351	9,041	5,560	94	16	17,243	776			14,703
1913											
1914	107	2,212	2,830	1,565			4,037	157			3,934
1915–33											
1934	3,637	127,113	90,757	58,671	19,838	1,587	7,000	259			187,630
1935	7,231	253,085	182,677	131,299	41,324	3,430					387,814
1936	8,928	312,480	200,045	154,935	60,070	5,526	520,000	23,920			496,861
1937	7,104	248,640	144,660	111,895	53,050	6,419	1,178,816	69,550	18,877	$1,227	437,731
1938	7,290	255,150	175,501	113,455	50,460	4,945	1,295,506	59,593	81,188	3,897	437,040
1939	3,803	133,105	92,929	63,079	34,977	3,638	797,470	37,470	673,700	35,032	272,324
1940	2,020	70,700	50,531	35,933	19,600	2,215	545,300	27,265	455,877	28,720	164,833
1941	5,260	184,100	65,433	46,530	57,400	6,773	1,263,000	71,991	1,252,000	93,900	403,294
1942	707	24,745	17,652	12,553	6,600	792	128,600	8,359	127,700	10,535	56,984
1943	20	700	828	589	210	25	3,650	237			1,551
1944	64	2,240	2,148	1,527			3,947	257			4,024
1945	346	12,110	7,527	5,353	1,153	138	12,400	806			18,407
1946	130	4,550	2,670	2,157	375	60	7,400	806	3,200	390	7,963
1947											
1948	132	4,620	3,264	2,954	1,767	383	20,644	3,695	23,320	3,101	14,753
1949	1,119	39,165	25,908	23,447	15,000	2,955	233,197	36,845	376,484	46,684	149,096
1950	1,650	57,750	31,125	28,168	35,000	7,280	335,100	45,239	276,000	39,192	177,629
1951	65	2,275	1,837	1,662	1,670	404	15,863	2,744	12,178	2,216	9,301
Total 1901–51	50,924	1,761,841	1,122,315	809,886	398,813	46,614	6,396,122	390,286	3,300,524	264,894	3,273,521
Total 1887–1951	58,748		1,315,264				6,503,028				3,541,440

less steeply than the main vein, whereas those on the west side of the main vein are nearly vertical. In many places the branch veins are of sufficient width and grade to be minable. Small veinlets of sulfide, with or without quartz, fill minor fractures in the Hillside mica schist, and locally some of these veinlets were minable and some were of higher grade than the main vein. Some faults that strike eastward were mineralized locally to form fissure-filled veins of high-grade gold-silver ore and the adjacent few feet of country rock was replaced to form ore of sufficient grade to be worth mining.

The grade of the ore has been fairly consistent throughout the mine, though a small increase in the amount of gold, sphalerite, and pyrite takes place in the lower levels. The vein averages 2½ feet in width in the upper levels and 4 feet on the 800-foot and 900-foot levels. From 1948 to 1950, the 800-foot, 900-foot and 1000-foot levels were extended south, and better than average grade of ore was found.

The north end of the 1000-foot level was driven in a large fault zone for about 75 feet and no continuous vein was found north of this zone in 1948. The longitudinal section (pl. 6) shows that the course of this drift was being run on a flatter part of one of the major north-dipping postmineral cross faults. On the 900-foot level this fault offsets the vein on the hanging-wall side of the fault for a distance of 20 to 25 feet to the east.

At both the north and south ends of the workings tendency of the vein to branch has hindered attempts to find profitable extensions of the vein. High-grade stringers of silver ore, however, have been found beyond both ends of the mine workings. Although the result of present exploration strongly suggests that the vein may be dying out to the north, no limit at depth has been found, and it is reasonable to assume that the vein may continue for several hundred feet below the 1000-foot level.

The postmineral faulting along the vein is of major economic importance, because in places the vein is absent and elsewhere it has been doubled. In other places the vein has been broken so completely as to form an unrecognizable part of the gouge. This faulted vein material is difficult to mine and has presented a problem in stoping. Along the vein the Hillside mica schist has been so dragged that foliation which normally dips at a high-angle is in nearly a horizontal position.

At a late stage in the postmineral faulting, the vein has been offset along cross faults striking east and dipping 25°–45° N., which may or may not follow mineralized fractures striking east. Generally, these late-stage cross faults have formed clean-cut breaks along which the vein on the hanging-wall side of the cross fault has been displaced from 1 to 25 feet to the east.

In 1941 the mill-head assays averaged: gold, 0.18 ounce per ton; silver, 4.1 ounces per ton; lead, 2.0 percent; zinc, 3.7 percent; and copper, 0.3 percent. The bottom of the vein has not been reached, and additional ore shoots will probably be found south of the stoped parts of the vein.

COPPER KING MINE

The Copper King mine is located 1½ miles south of Bagdad and is reached by 7 miles of dirt road in fair condition that connects with the Bagdad-Hillside road, 2 miles southeast of Bagdad. The mine is owned and operated by E. A. Scholz and J. H. Cazier.

The Copper King claim was located on January 1, 1881 by William Waters. It was relocated on March 28, 1891 by Fred Maroney and John Lawler and patented by them May 1, 1893. No ore was shipped until 1917, when the Arizona Hillside Development Co. obtained an option on the Copper King claim and acquired surrounding claims. From 1917 to 1921, the mine operated continuously with considerable exploration, development, and production in this period. In 1925 the World Exploration Co. obtained control, shipping ore until 1927, but with the decline in zinc prices, ownership reverted to John Lawler's heirs, M. L. Lynch and J. W. Lawler.

During World War II, the mine was leased to Valerio Rossi who mined pillars of massive-sulfide ore that contained as much as 50 percent of zinc, 3 to 4 percent of lead, and 2 to 3 percent of copper. Premiums were paid for these metals. In addition, Rossi selectively mined oxidized ore near the surface that yielded shipments containing 3 to 4 percent copper and 10 to 27 percent zinc.

The Goodwin Mining Co. purchased the mine in 1948 and produced about 4,800 tons of massive sulfide ore, largely from the 380-foot level. The grade of 4,500 tons averaged 23.27 percent zinc and 2.18 percent copper. Scholz and Cazier purchased the property in 1950 and by the end of May 1952 they had mined 5,784 tons of massive sulfide ore of comparable grade.

Past production (table 9) from the Copper King mine of recoverable gold, silver, copper, lead, and zinc has a total value to the end of 1951 of $1,526,577; zinc ranks highest, 13,466,268 pounds with a value of $1,310,910. Copper, lead, and silver have had about equal value, but the gold production, 120 ounces, with a value of $3,741 has been small. The Copper King mine has had three periods of production, 1917–20, 1925–27, and the last, starting in 1942 was continuing in 1952.

The details of the local geology are shown on figure 26 and a composite map and a section of the underground workings are given on figures 27 and 28 respectively. A 624-foot inclined shaft provides access

TABLE 9.—*Metals produced, Copper King mine, 1917–51, in terms of recoverable metals*

[Compiled by the U. S. Bureau of Mines and published with permission of the owners. Ceiling prices used during periods of premium payments]

Year	Gold		Silver		Copper		Lead		Zinc		Total value
	Ounces	Value	Ounces	Value	Pounds	Value	Pounds	Value	Pounds	Value	
1917	5	$103	2, 568	$2, 116	5, 350	$1, 461	21, 400	$1, 840	422, 402	$43, 085	$48, 605
1918	3	62	1, 960	1, 960	7, 700	1, 902	16, 200	1, 150	357. 380	32, 522	37, 596
1919	-----	-----	-----	-----	-----	-----	-----	-----	1, 717, 000	125, 341	125, 341
1920	-----	-----	-----	-----	-----	-----	69, 790	5, 583	1, 457, 296	118, 041	123, 624
1921–24	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1925	-----	-----	896	621	7, 556	1, 073	5, 351	466	184, 466	14, 019	16, 179
1926	22	455	28, 539	17, 808	126, 408	17, 697	313, 427	25, 074	3, 949, 154	296, 187	357, 221
1927	2	41	934	529	6, 915	906	13, 113	836	141, 232	9, 039	11, 341
1928–41	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1942	2	70	817	581	13, 936	1, 672	-----	-----	-----	-----	2, 323
1943	5	175	3, 588	2, 551	39, 925	4, 791	8, 404	546	48, 000	3, 960	12, 023
1944	15	525	8, 515	6, 055	65, 556	7, 867	89, 853	5, 840	468, 500	38, 651	58, 938
1945	16	560	9, 795	6, 965	58, 476	7, 017	128, 416	8, 347	1, 021, 925	84, 309	107, 198
1946	9	315	6, 317	5, 104	34, 615	5, 608	96, 400	10, 508	498, 000	60, 756	82, 291
1947	2	70	1, 864	1, 687	13, 875	2, 914	25, 937	3, 735	307, 750	37, 238	45, 644
1948	4	140	2, 431	2, 200	8, 987	1, 950	45, 473	8, 140	399, 480	53, 131	65, 561
1949	6	210	3, 847	3, 482	59, 108	11, 644	61, 217	9, 672	950, 934	117, 916	142, 924
1950	20	700	960	869	51, 485	10, 709	22, 576	3, 048	601, 645	85, 434	100, 760
1951	9	315	4, 345	3, 932	42, 902	10, 382	17, 902	3, 098	941, 104	171, 281	189, 008
Total	120	3, 741	77, 376	56, 460	542, 794	87, 593	935, 459	87, 873	13, 466, 268	1, 310, 910	1, 526, 577

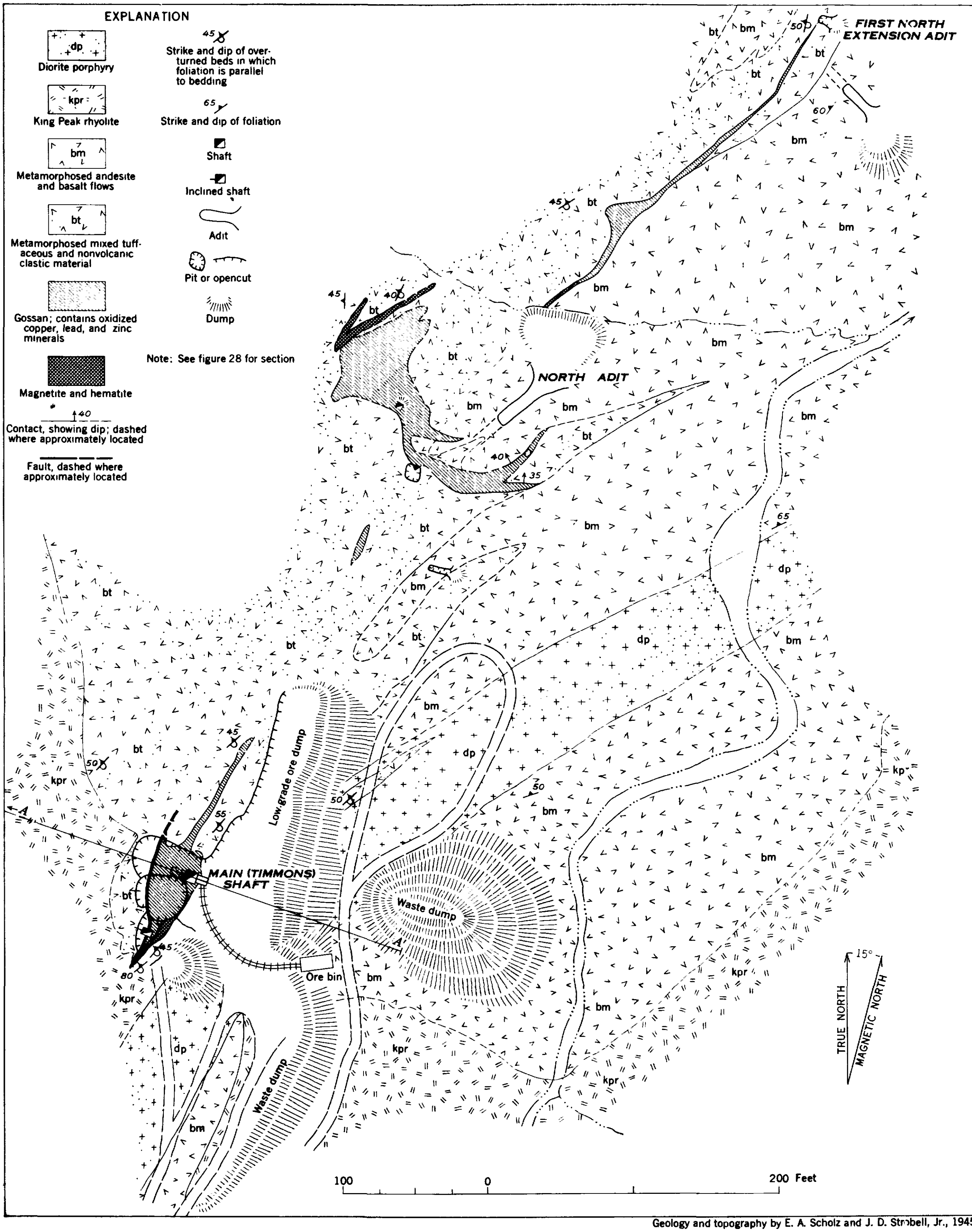


FIGURE 26.—Geologic map of the Copper King mine area, Bagdad, Ariz.

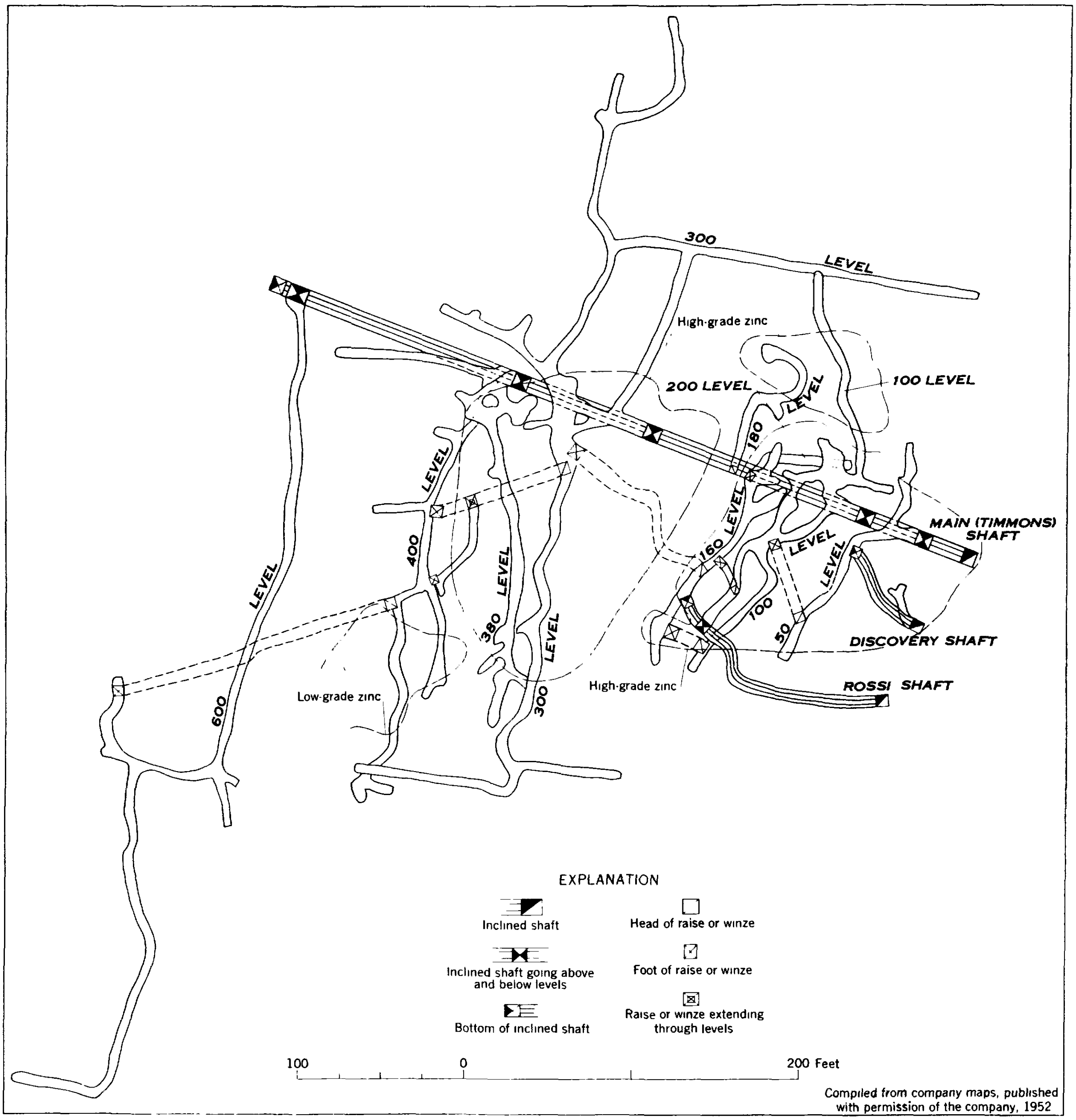


FIGURE 27.—Composite map of levels in the Copper King mine, Bagdad, Ariz.

to nine irregularly spaced levels, but only the 380-foot and higher levels were accessible in 1952. More than 4,000 feet of workings are reported; probably, inclined and vertical openings as well as drifts and crosscuts are included in this figure.

The exposed ore is confined to a unit of tuffaceous sedimentary rock of the Bridle formation. A diorite porphyry dike, 80 feet wide, crops out less than 50 feet southeast of the collar of the shaft, but no information is available as to the effect of this dike on the ore. Partial replacement of a small diorite porphyry dike in the north part of the workings indicates that the mineralization is later than the dike, but the physical and chemical character of the diorite porphyry may not have been favorable for the formation of large minable lenses of ore in the larger dike.

The essential control in ore deposition is a series of small interlacing faults that form a zone parallel to the bedding structure of the tuffaceous unit of the Bridle formation. Two major lenses of ore, one north and one south of the inclined shaft, center about the 100 level (fig. 28), and a third major lens, south of the shaft centers about the 300 level. Exploration in 1952 was directed to the north of the shaft on the 300 level to find out if a lens of comparable size is present there.

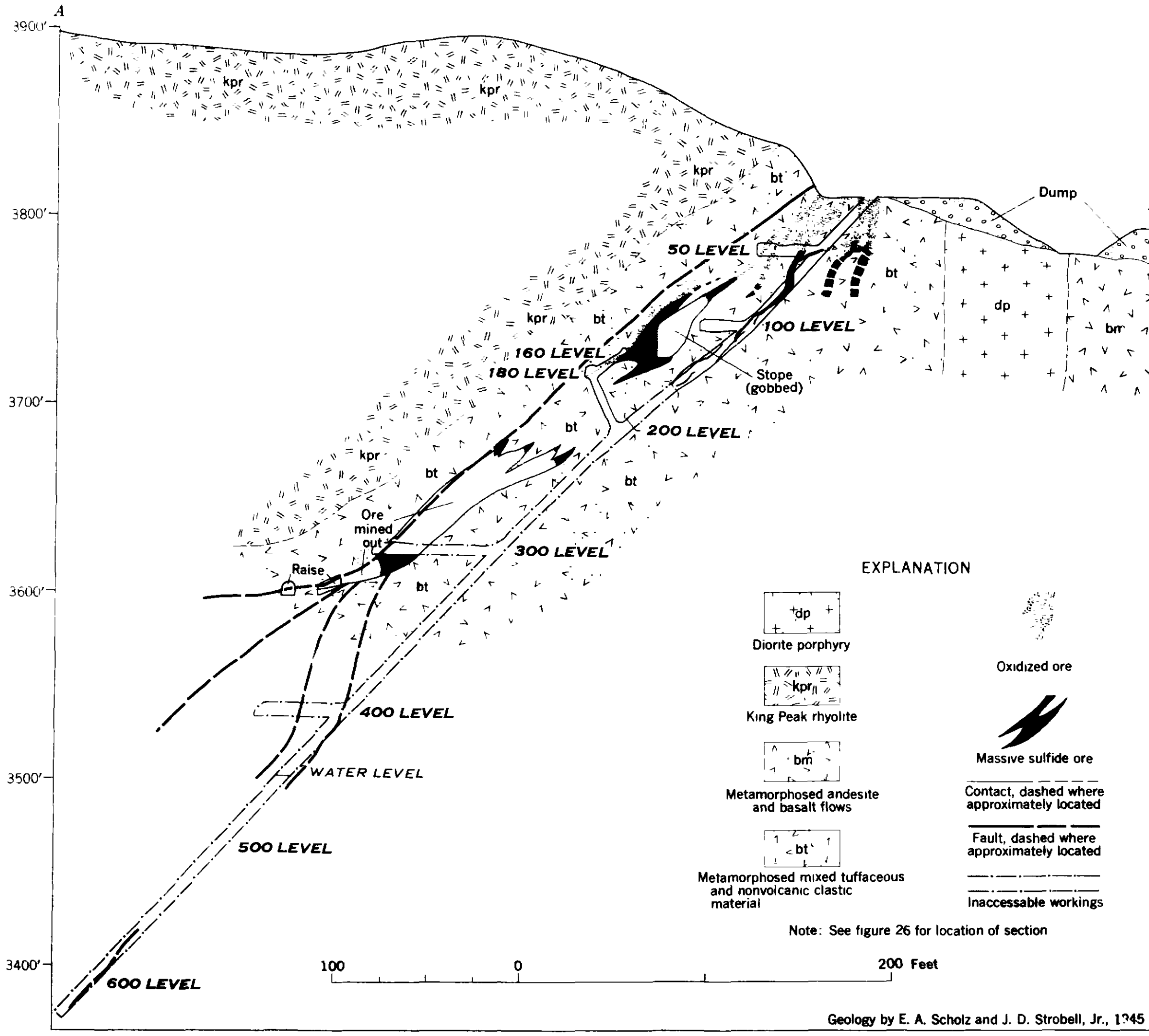


FIGURE 28.—Section through Copper King mine, Bagdad, Ariz.

Evidence indicates that some of the lenses of ore may dip more steeply into the footwall than the main fault zone, and additional small lenses may be found in the footwall zone.

Private reports on the mine indicate that on the lower levels a mineralized zone 10 feet wide contains 3–8 percent zinc, a marked decrease in grade, as compared with the massive-sulfide lenses on the higher levels.

OLD DICK MINE

The Old Dick mine is located 2¾ miles south-southwest of Bagdad and 1½ miles south of the Copper King mine. A short truck road connects with the Copper King-Bagdad-Hillside road.

The Old Dick claim was located in 1882 by William Waters, who sold it to John Lawler 9 years later. Lawler obtained a patent for it in 1892. Although Lawler added to his holdings in the vicinity, there was not production until E. G. Green and associates, under lease, encouraged by a premium price for copper, mined oxidized copper ore from November 1943, to June 1944, from a stope in the northeastern end of the mineralized zone. Additional ore was taken from surface cuts. About 500 tons of ore was shipped, averaging about 10 percent copper, 3.9 percent zinc, and 0.55 ounce of silver per ton.

Early exploration work on the Old Dick claim included 2 shafts, 50 and 67 feet deep, and an adit level to connect with the more southerly shaft (shaft 1). A vertical winze was sunk 68 feet from the adit level (no. 1 winze, fig. 29). The upper adit was begun in 1944 but abandoned after massive sphalerite was encountered 100 feet from the portal.

In 1947, the Goodwin Mining Co. purchased the Old Dick mine and found lenses of massive zinc sulfide on the adit level, 120 feet northeast of winze 1 and this

TABLE 10.—*Metals produced, Old Dick mine, 1943–51, in terms of recoverable metals*

[Compiled by the U. S. Bureau of Mines and published with permission of the owner. Ceiling prices used during periods of premium prices]

Year	Gold		Silver		Copper		Lead		Zinc		Total value
	Ounces	Value	Ounces	Value	Pounds	Value	Pounds	Value	Pounds	Value	
1943	3	$105	90	$64	25,950	$3,114					$3,283
1944	4	140	154	110	66,844	8,021					8,271
1945-46											
1947	1	35	139	126	28,096	5,900	1,242	$178	189,930	$22,982	29,221
1948	52	1,820	8,958	8,107	381,845	82,860	180,786	32,360	4,220,000	561,260	686,407
1949	22	770	4,207	3,807	496,475	97,806	39,412	6,227	3,173,038	393,457	502,067
1950	85	2,975	2,915	2,638	173,900	36,171	53,500	7,223	2,033,200	288,714	337,721
1951	61	2,135	6,100	5,520	617,945	149,543	83,900	14,514	4,044,850	736,163	907,875
Total	228	7,980	22,563	20,372	1,791,055	383,415	358,840	60,502	13,661,018	2,002,576	2,474,845

company mined primary zinc sulfide ore intermittently. S. R. Hullinger and F. G. McFarland purchased the mine in October 1950 and started mining in March 1951, and sold the mine to the Manhattan Consolidated Mines Development Co. in October, 1951. The mine has been operated continuously from April 1951, to the present (July 1952), and from March 1951 to June 1952, 23,509 tons of ore have been produced. Most of this ore ranged in grade from 15.76 to 22.20 percent zinc and 2.22 to 3.45 percent copper, except for a 3-month period when shaft 2 was being sunk, and lower grade ore was taken from higher levels. Metal production is summarized in table 10.

A composite map of the underground workings is shown on figure 29. The main workings consist of the adit level, level 50, level 100, level 150, and level 225. Only the last 2 levels connect with shaft 2.

Figure 30 is a map of the surface geology. The ore trends northeast in foliated lava flows in an embayment of the Bridle formation into Dick rhyolite. The ore zone of massive sulfide that crops out at the surface, indicated by heavy gossan is near Dick rhyolite, and on lower levels of the mine rhyolite is near the southeastern margin of the ore zone. As shown in the transverse section (fig. 29, *A–A'*), the ore zone consists of separate lenses of massive sulfide; some are vertical in part and some dip steeply westward. It appears that the lenses dipping west are controlled by foliation dipping westward in the lava flows; some faults are parallel to the foliation. The vertical segments of massive sulfide appear to be controlled by a fault zone along the southeastern margin of the Bridle formation.

As shown in longitudinal projection (fig. 31), the ore zone plunges to the south at an angle of about 35°. The lenses of massive sulfide overlap to some extent along the strike of the ore zone, and in places they are separated by waste rock.

The maximum width of the massive-sulfide lenses is about 35 feet, thinning toward the edges. On level 225 the length of the ore zone is about 300 feet (fig. 31).

The primary sulfides are found not only in the massive lenses, but also occur disseminated in rock particularly to the west of the massive-sulfide lenses. This rock is too low in grade to be worth mining under present conditions, but represents a future reserve of zinc and copper.

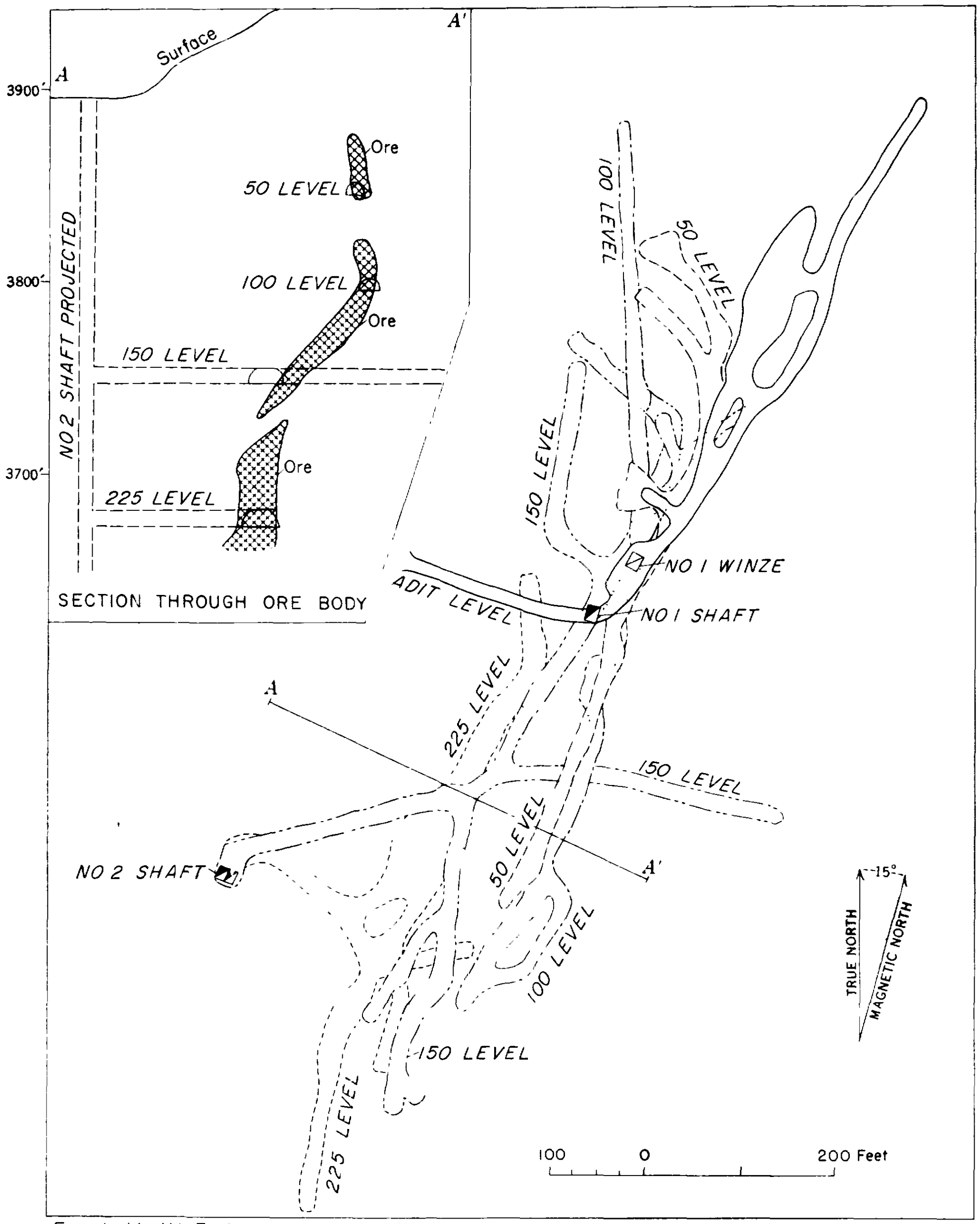
The wide belt of intensely altered volcanic rocks west of the diabase (fig. 30) is a potential area for exploration because similar altered rocks contain the massive-sulfide lenses of the Old Dick mine. It is true that this wide belt of altered rock contains no gossan formed from sulfides but the presence of disseminated pyrite is indicated by abundant limonite in cavities, and it is possible that massive-sulfide lenses may be present that are not cut by the present erosion surface.

COMSTOCK-DEXTER MINE

The Comstock-Dexter mine is located along Butte Creek a little more than 2 miles north of Bagdad and on the south extension of the Hillside fault (and vein). The Comstock and Dexter patented claims having an area of 26 acres are owned by the Comstock-Dexter mines, Inc., T. F. M. Fitzgerald, president.

The Comstock claim was located on March 1, 1892, by Paul Dillon, J. F. Dillon, and Joseph Howell. The Dexter claim to the south was located on January 1, 1896 by L. J. Webber and relocated on May 19, 1896 by Jacob Reese. Before 1901, some shipments of high-grade ore were made from the two claims, and some of the oxidized ore was crushed in a 5-stamp mill recovering $18,000 in gold and silver by amalgamation (Hoagland, 1937). As the mine workings were extended to greater depths and reached sulfide ores, the stamp mill was unable to recover sufficient gold and silver from the ore to warrant continuation of the operation. On November 29, 1907, the Comstock-Dexter claims were patented by A. C. Gilmore, W. W. White, and J. F. Dillon. Later John Lawler bought Mr. White's interest in this claim.

T. F. M. Fitzgerald became interested in the Comstock-Dexter claims in 1930 and purchased one-half interest and took a lease on the other half. He also purchased adjoining unpatented claims and gave an option to purchase the entire group to the General



Furnished by K L Erickson, superintendent, 1952

FIGURE 29.—Composite map of levels and section through the Old Dick mine, Bagdad, Ariz.

Minerals Co. This company, with Mr. Fitzgerald in charge, carried on development for about a year in 1932–33, but the company had financial difficulties and receivership followed. Later litigation confirmed Mr. Fitzgerald's title to the property, and in January 1934, he organized the Comstock-Dexter Mines, Inc. A total of $133,000 was obtained by stock sale to carry on development work and to construct buildings and a 100-ton mill. The mine was in operation during 1938 and according to the records of the U. S. Bureau of Mines, production for that year totaled 410 ounces of gold, $14,350; 6,500 ounces of silver, $4,202; 1,363 pounds of copper, $134; and 8,080 pounds of lead, $372; for a total value of $19,058.[4] The company ceased operations because of new financial difficulties and all the surface buildings were sold and removed.

The mine is inaccessible, owing to caving of the shaft and the adit level, and no maps of the underground workings are available. The original work was done from an adit driven eastward from the floor of Butte Creek, but when the last mining activity was carried on between 1930 and 1938, a shaft was sunk on the vein north of Butte Creek and 4 connecting levels were driven; these totaled about 4,000 feet of workings—chiefly drifts along the vein. The vein is well

[4] Figures published with the permission of T. F. M. Fitzgerald.

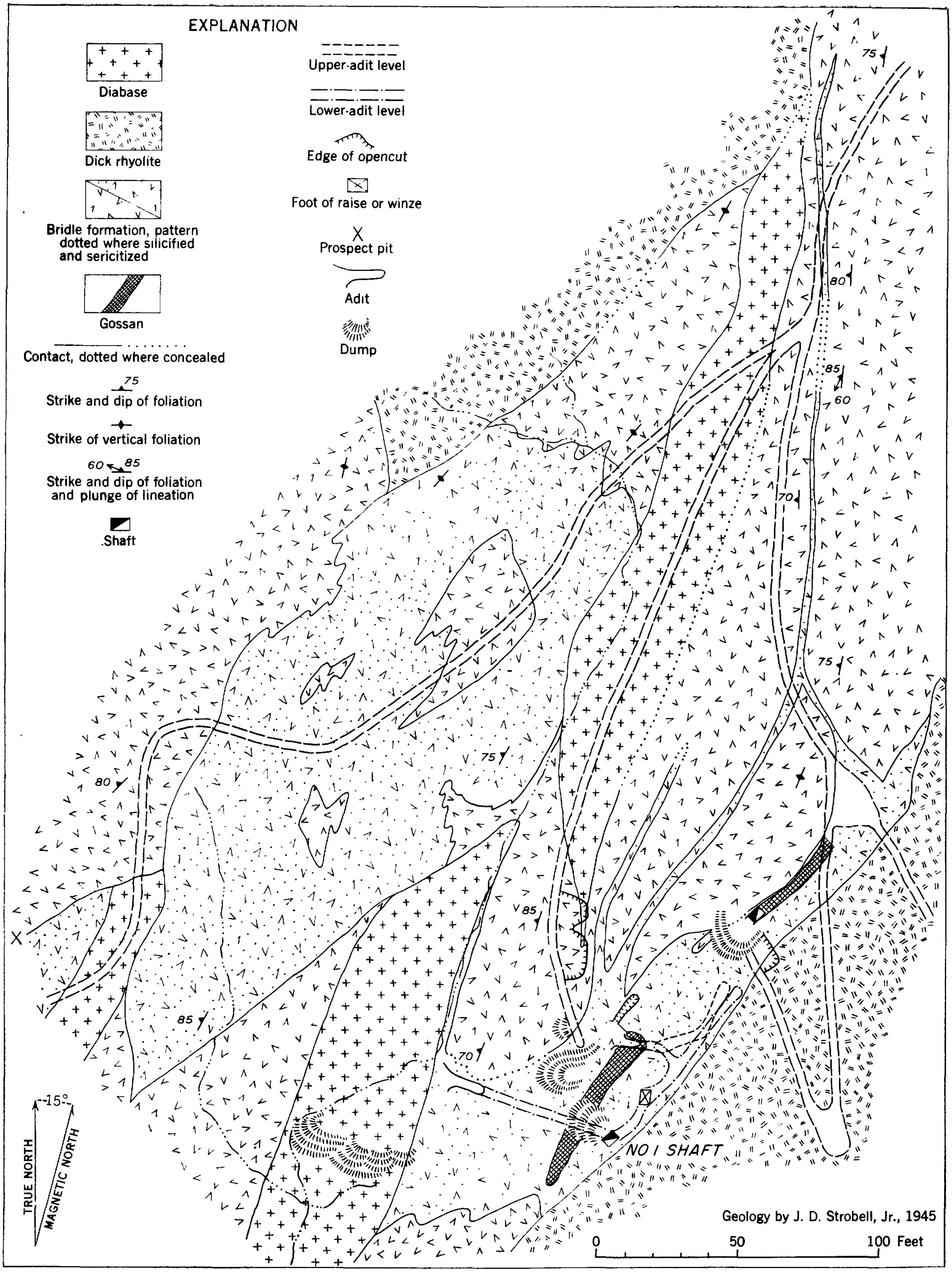


FIGURE 30.—Geologic map of the Old Dick mine area, Bagdad, Ariz.

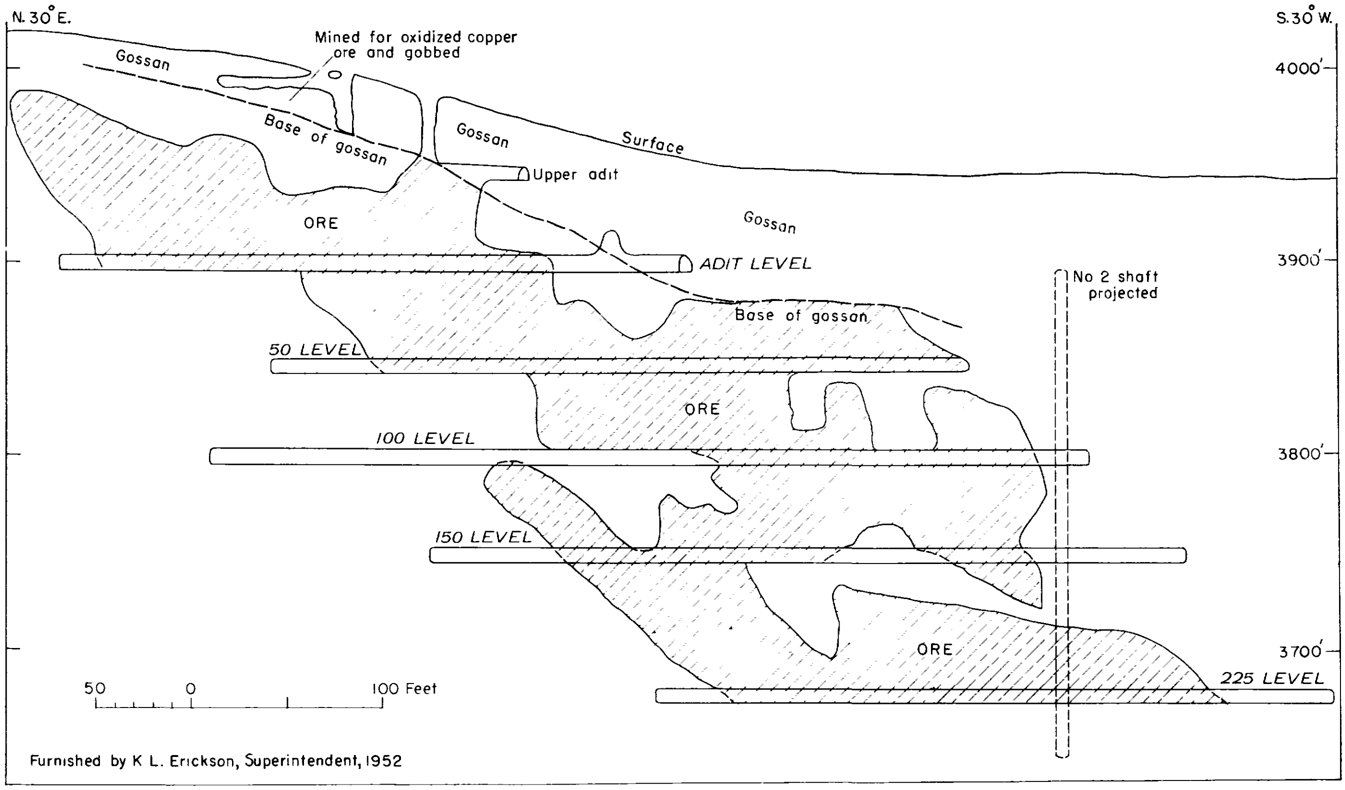


FIGURE 31.—Longitudinal projection through the Old Dick mine, Bagdad, Ariz.

exposed north of the caved shaft with 3 feet of broken and limonitic-stained quartz, and, according to T. F. M. Fitzgerald (oral communication), 2 veins intersected in the vicinity of the shaft so that the ground was very heavy. These veins separated to the north, but with the same general strike, although one vein had a steeper westerly dip than the other. In development, drifts were driven along one vein with crosscuts to the other. Most of the drifts were driven to the north of the shaft, as the south drifts caught too much water from Butte Creek. The vein can be followed south along Butte Creek for several thousand feet where there are some prospect shafts, and two associated veins have been prospected. The south extension of the vein carried gold and silver, but not as much as in the ore shoots in the developed ore body (T. F. M. Fitzgerald, oral communication).

Hoagland (1937) states that 47,745 tons of probable ore were present in the mine in 1937, averaging $13.48 per ton in gold and silver. No figures are available as to the tonnages mined in 1938.

COWBOY MINE

The Cowboy mine is located 2½ miles southeast of Bagdad and less than 1 mile south of the Bagdad-Hillside road. The access road to the Cowboy mine was impassable in 1945. The first work on the claim was done by Marsh Darnell for John Lawler about 1889, but the first record of any mining is for 1911. In 1924 Grover G. Gray relocated the claim, adding five additional claims in 1936 to form the Cowboy group of unpatented claims. Production since 1911 has totaled $9,173; the chief return has been in gold, $4,779, but silver, copper, and lead have been recovered. The ore that has been mined is reported to have ranged in value from $15 to $1,200 per ton, and the total production was about 350 tons. A shaft about 200 feet deep gives access to about 400 feet of drifts, north and south of the shaft.

The Cowboy vein is a small irregular quartz vein striking N. 10°–30° W. and dipping 50°–80° W. It has a maximum width of 3 feet, but commonly is not more than 1 foot wide. The vein crops out in the Hillside mica schist near its contact with Lawler Peak granite.

Several oral reports stated the gold-silver content is greater in the oxide zone, which ranges from 25 to 150 feet in depth. The workings were under water in 1945.

STUKEY MINE (LAWRENCE GROUP OF CLAIMS)

The Stukey mine is located a little more than 2 miles south of Bagdad and about 1 mile east of the Mountain Spring fault. The vein is crossed by the Copper King-Hillside road. The first prospecting was done by

Mr. Lawrence in the early 1900's. In 1916, C. C. Stukey and Charles Crosby shipped some ore to the Humbolt copper smelter for use as flux. The last shipment was made in 1938 by E. G. Chapman. The mine is now called the Stukey mine, but in some of the older records it is known as the Lawrence group of claims.

The chief recoverable metal has been lead, totaling 38,743 pounds; in addition, 7 ounces of gold, 355 ounces of silver, and 114 pounds of copper have been recovered; total value to 1945 is $3,588.

The workings consist of many small pits along the vein, a prospect adit, a shaft at the south end of the vein, and the main shaft, north of the road. No information is available as to the size of the workings.

The Stukey vein is a narrow quartz vein, commonly less than 1 foot wide and strikes nearly due north and dips vertically. It cuts across Hillside mica schist and Lawler Peak granite, and is more continuous in the granite, for in the schist it tends to split along the foliation. Generally the Stukey vein and extensions of it can be followed along the strike for about 1 mile. Pyrite, galena, sphalerite, and chalcopyrite in less amount, are the principal primary sulfides. Along the vein, the sulfides crop out in a few places but at the main shaft the oxidized zone appears to be about 50 feet deep. Aside from quartz, in the oxidized zone, minerals noted are largely cerussite and small amounts of anglesite associated with limonite, and malachite and chrysocolla, as stains.

MOUNTAIN SPRING MINE

The Mountain Spring claim, a patented claim, is located along the south end of the Mountain Spring fault, a little more than 3 miles south-southwest of Bagdad. The claim was owned by M. L. Lynch and J. W. Lawler in 1945. Workings consist of two shafts, each about 45 feet deep, and several cuts and pits. It is reported that small shipments of hand-sorted ore have been made intermittently since 1942.

Several parallel, interlacing and branching quartz veins contain sulfides. These veins average about 1 foot or less in width, but a maximum width of 3 feet was observed. The veins all dip steeply and one can be traced for about 1,500 feet. The veins were formed along the Mountain Spring fault and are bordered by Hillside mica schist and Lawler Peak granite to the east and by Bridle formation to the west. In the shaft at Mountain Spring the vein consists of a series of parallel quartz and sulfide stringers separated by sericite schist. Later faulting has pulverized the vein material in places. The primary sulfides are galena, sphalerite, chalcopyrite, and pyrite. The depth of the oxidized part of the veins ranges from 1 foot to 50 feet. Cerussite, anglesite, chrysocolla, malachite, and hemimorphite were observed on the dump. Wulfenite crystals were found near the shaft at Mountain Spring.

KYEKE MINE

The Kyeke mine is located on the northwestern slope of Boulder Canyon 2½ miles northwest of Bagdad. Russell Samson located five claims in 1934. The only production of gold and silver, is from the Kyeke claim. The first work was done at the upper adit (fig. 32), which follows a crushed zone for 50 feet, and also on an underhand stope, which was started near the portal. About 60 tons of oxidized ore reportedly was shipped in 1936 and 1937, and yielded 15 ounces of gold, 29 ounces of silver, for a total value of $548. In 1937, Mr. Samson drove a lower adit and a connecting inclined raise to the stope (fig. 32). Later he sunk a vertical winze along ore at the top of the raise and drove a short sublevel along the ore zone.

The ore occurs in the upper adit in a crushed zone 3 to 5 feet wide striking west of north and dipping 35° to 40° to the east. The ore is oxidized but contains kernels of fresh sulfide, chiefly arsenopyrite and a little pyrite, in quartz. No sulfides occur along the east low-dipping fault that appears in the lower adit, but sulfides occur in bunches along a steep fault in the winze and northern sublevel, whereas the low-dipping fault, followed by the raise, passes above the hanging wall of the ore zone on the upper level. The change in dip of the ore zone may be due to the upper fault acting as a dam to the mineralizing solutions causing deposition along the lower dipping fault. A second possibility is that the low-dipping fault dragged the ore from the steeper dipping mineralized zone. Sufficient development work has not been done to determine whether the mineralized zone in the winze continues to the level of the lower adit. The dimensions of the partly stoped ore shoot are not known.

A comparable crushed zone, 1 foot wide, of quartz and partly oxidized arsenopyrite crops out in the ridge to the south of the portal of the lower adit. Here the strike of the crushed zone (vein) is N. 25° E. and the dip is 40° E. Hand-sorted ore from this zone is reported to average $27 per ton in gold and silver. Exposures are too poor to determine whether this zone is a southern extension of the Kyeke vein or a parallel structure.

MAMMOTH PROSPECT

The Mammoth copper prospect is located 2½ miles west-southwest of Bagdad along Mammoth Wash. Twelve unpatented claims form the Mammoth group of claims, held by M. J. Lawler, W. A. Lawler, and Mrs. Mary Lawler. The Mammoth claim and several of the associated claims were first located in 1906 by

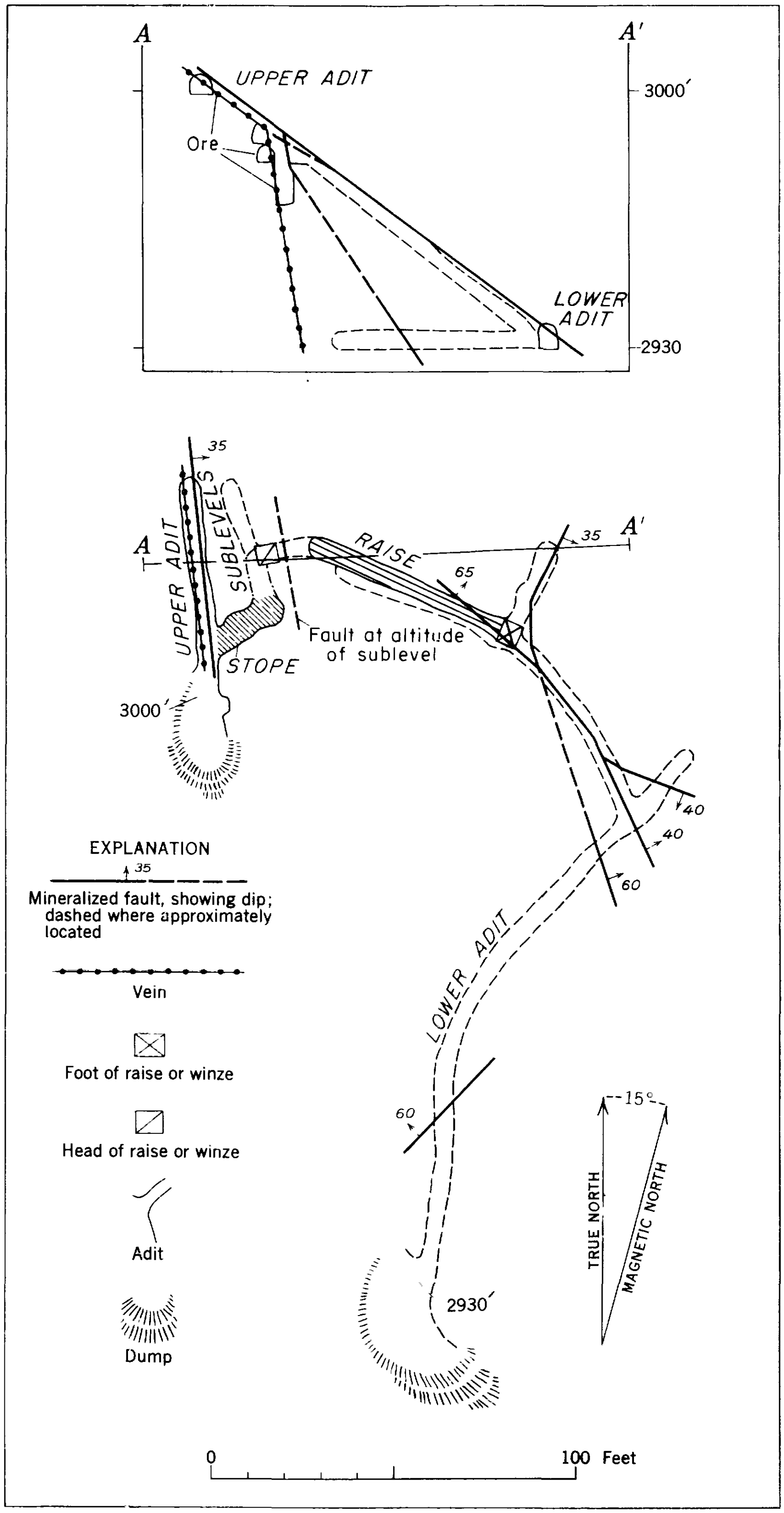
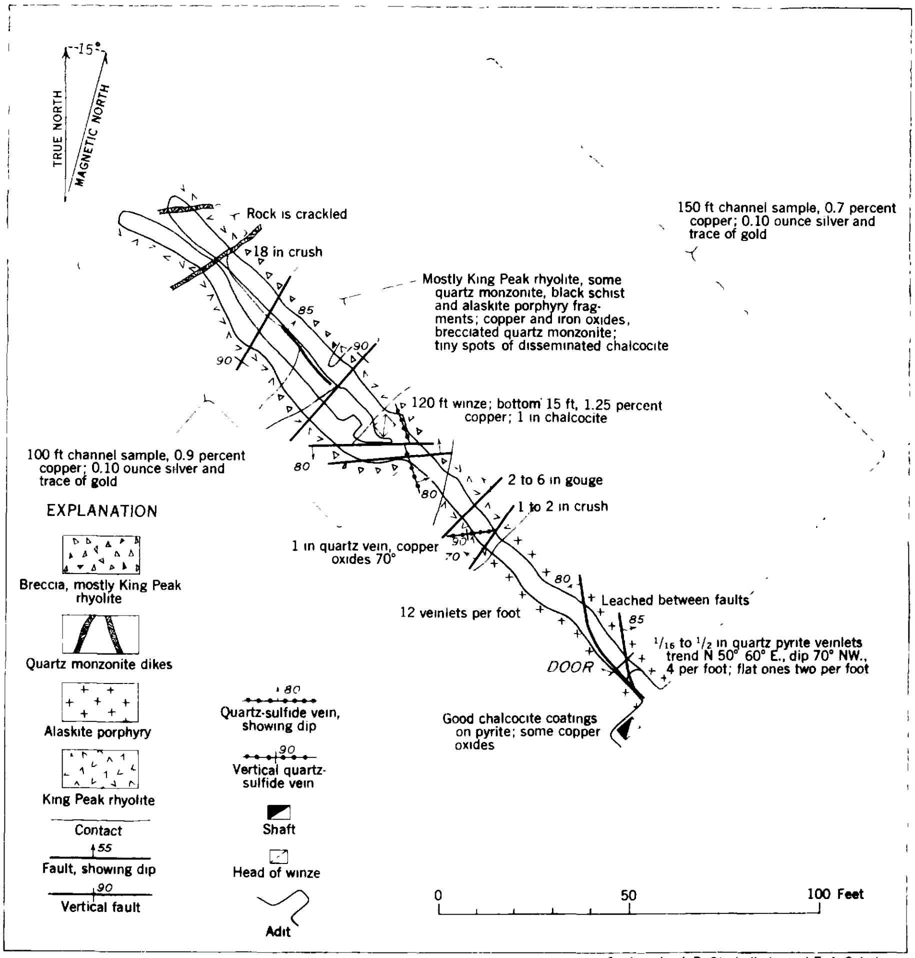


FIGURE 32.—Map of workings and sections through Kyeke mine, Bagdad, Ariz.



Geology by J. D. Strobell, Jr. and E. A. Scholz.
Mapped by Brunton compass and tape, 1945

FIGURE 33.—Map of Mammoth prospect, Bagdad, Ariz.

William Lawler and M. A. Lawler. Workings on the Mammoth claim extends into the adjacent Monitor claim and consists of an adit 125 feet long and a parallel adit, 100 feet long, branching from it (fig. 33). A 25-foot shaft was sunk from the south side of the adit portal, and a winze 120 feet deep was sunk from the adit. Several pits are on the surface above the adit. No ore has been shipped from the property.

The prospect is at the south end of a mass of King Peak rhyolite, which is surrounded and brecciated along their contact by younger intrusive alaskite porphyry. A series of breccia pipes of considerable extent are grouped south of the prospect. Small dikes and stocks of quartz monzonite surround the prospect.

The better grade copper-bearing mineralized rock has been localized along fractures striking N. 40°–80° E. and dipping steeply, and in brecciated rock formed where the northeast fractures are closely spaced. Extension of the northeast mineralized fractures into a breccia pipe to the south (pl. 3) indicates that the pipe was formed before the fractures, therefore the pipe has no direct relation to the mineralized breccia that was formed by close spacing of the fractures. These northeast mineralized fractures have a maximum concentration of 12 per foot and become less common to the southeast and northwest of the adit portal. Along the strike the fractures die out 150 feet to the northeast and 400 feet to the southwest of the adit.

Near the face of the adit the King Peak rhyolite is crackled and intruded by two narrow dikes of quartz monzonite. At the edge of the adjacent breccia pipe a large dike of brecciated quartz monzonite is present.

Postmineral faulting is of some importance, although where offsets could be measured, they were only 6 inches to 3 feet across.

The primary minerals are quartz, pyrite, chalcopyrite and a small amount of molybdenite. Gold and silver are also present. These minerals occur in veinlets along the northeast fractures and as fillings in the interstices of the brecciated rock, and as disseminated grains. Some sericite is associated with the quartz.

The copper content has been increased by supergene enrichment, resulting in some replacement of the chalcopyrite and pyrite by chalcocite. The adit level is probably near the top of the enriched zone because in some of the more permeable zones cut by the adit, rock is leached of copper, and maroon "relief" iron oxide after chalcocite is present. M. J. Lawler reports that chalcocite was found in the bottom of the 120-foot winze, and contained 1.25 percent copper in the lowest 15 feet. More exploration in depth is needed before any estimates can be made of the thickness of the chalcocite zone. In the leached zone at the surface, azurite, malachite, chrysocolla, and cuprite were found, and chalcanthite coats the walls of the adit.

The available assays were obtained from M. J. Lawler, one of the owners of the prospect, who cut two channel samples, one 150 feet along the adit, and the other 100 feet along the south wall of the branch drift. The former sample assayed 0.7 percent copper, 0.10 ounce of silver per ton, and a trace of gold. The latter sample assayed 0.9 percent copper, 0.10 ounce of silver per ton. These assays indicate a fairly low-grade copper deposit.

When the price of copper justifies it, the Mammoth prospect will deserve additional exploration to determine grade, size, and continuity of the deposit, which, based on surface exposures, might contain about 6,000 tons of ore per foot of depth, ore that may have a grade similar to that indicated by the assays from the adit and winze.

GOODENOUGH MINE

The Goodenough patented claim is located about 1 mile southwest of the Hillside mine on the west bank of Boulder Creek. It is owned by M. L. Lynch, J. W. Lawler, Mrs. E. W. Blake, and Mrs. Elmer Wells. A copper-lead-zinc quartz vein, carrying some gold and silver, is in the rhyolite breccia plug. A shaft has been sunk on the vein and a small shipment of ore was packed out on burros to the road at the Hillside mine and shipped to the smelter, but the arsenic content was reported too high for shipping ore. The metals recovered by the smelter were gold, silver, and copper.

CUPRUM CLAIM

The Cuprum patented claim is located 2 miles northwest of Bagdad along Boulder Creek and is owned by M. L. Lynch and J. W. Lawler. A 30-foot adit has prospected a quartz vein 1 foot wide and striking N. 45° W. and dipping 80° SW. The vein is oxidized and crushed by postmineral faulting. Vein quartz containing stringers of galena, sphalerite coated by covellite, and pyrite, is found on the dump, presumably from a winze at the face of the adit.

VIDANO CLAIMS

Eight unpatented claims, Vidano 1 to 8, are held by Bert Vidano who located them in 1943, 2½ miles north of Bagdad and west of the Hillside mine road. They include several quartz veins 3 inches to 1 foot wide in the Lawler Peak granite. These veins have a general north strike and a steep dip. Several trenches, shafts, and short adits have been excavated along them. A long adit was started to intersect these veins at depth; the portal is to the west along the old Hillside road. The adit was inaccessible and no information is available as to its length. Most of the vein outcrops are barren except for a little limonite and malachite stain. Locally, sulfides occur in the quartz, and a shipment in 1936 of hand-sorted galena is reported to have contained gold, silver, and copper.

NIAGARA CLAIMS

Six patented claims, Niagara 1 to 6, are located along Niagara Creek and are owned jointly by Vera Voge and the Coronado Development Corp. The most promising mineralized ground appears in the breccia pipes, where there is evidence of copper mineralization. Most of the exploration has been limited to the most northerly breccia pipe along Niagara Creek, where a 150-foot adit has been driven in the pipe. A drift 80 feet long follows a north-northwest striking fault, and another drift 50 feet long follows in part a west-northwest fault. Pyrite having a thin coating of chalcocite is found in the quartz cementing the breccia. Chalcanthite and some carbonates of copper are found near the portal. No assays are available, but the copper content is estimated to be less than 1 percent.

CHANCE CLAIMS

The area between the Bagdad patented claims and the Copper King patented claim, contains 19 unpatented claims, Chance 1 to 19, located originally by Fred Gibbs in 1922 and in 1945 held by Alec Lucy and Frank Morton. Several prospect pits are on the claims, but the most extensive exploration is in a breccia pipe near the headwaters of Alum Creek, a little more than half a mile slightly west of north of the Copper King mine. An adit 170 feet long driven into the breccia revealed pyrite coated with chalcocite and some chalcopyrite almost entirely replaced by chalcocite, embedded in the cementing quartz. It is reported that sampling of this adit indicated about 1 percent copper. Samples taken in an inclined diamond-drill hole are said to have averaged about 0.5 percent copper, which suggests that the adit was driven along a zone slightly enriched in chalcocite.

TUNGSTONA MINE

The Tungstona mine is located along Boulder Creek in the northeast part of the Bagdad area. The unpatented claims covering the wolframite-bearing veins are owned by Russell Samson. The Hillside Mining and Milling Co. has a lease and option to purchase the claims. This company, in 1952, had driven an adit level north from Boulder Creek to cross the eastward-trending vein system. The company plans to drive raises to the surface and mine the tungsten ore from surface downward, by a series of glory holes, using the adit to haul ore to the south side of Boulder Creek. The ore will be trucked to the Hillside mill for concentration. E. G. Green (oral communication) has stated that some disseminated scheelite was found underground in siliceous pyritic material between the wolframite-bearing veins.

Mr. Green also stated that about 2,500 tons of ore has been mined from the south side of Boulder Creek for use in mill testing. The company plans to do most of its first mining in the vein system north of Boulder Creek.

In 1944, Russell Samson and associates erected a 10-ton mill and a concentrating table to separate the wolframite, and Mr. Samson obtained 90 pounds of concentrate containing 30 percent WO_3 from 7 or 8 tons of mineralized rock from an open cut in the vein system south of Boulder Creek. In order to obtain additional information as to the grade, in 1944 we cut two channels across both mineralized zones; one sample, 8 feet long, from north of Boulder Creek contained 0.16 percent WO_3; the other sample, 11.4 feet long, from south of Boulder Creek contained 0.13 percent WO_3. These determinations were made by S. F. Grimaldi of the Geological Survey. Spectrographic analyses of the same samples, made by K. J. Murata, also of the Survey, indicate 0.05 percent BeO in the north zone and 0.2 percent BeO in the south zone. Minor constituents include lead, bismuth, molybdenum, and vanadium. Eighteen tons of mineralized rock were blasted from the exposures south of Boulder Creek by Russell Samson in 1944. The broken rock was ground in a ball mill and a 275-pound sample was split from the discharge. In a smaller split from the sample, F. S. Grimaldi found 0.21 percent WO_3, and Esther Claffy of the Survey determined the BeO content, by spectrographic analysis, to be 0.2 percent.

E. G. Green has reported that the development work in 1952 has revealed appreciable tonnages of higher grade WO_3 content, averaging 0.3 percent. A deposit of such low-grade ore can be mined only when prices for tungsten are as high as they were in 1952. Continued high prices for tungsten and effective separation of the beryl would insure continued operations. The length of the outcrops of the tungsten-bearing veins indicate that appreciable resources of WO_3 and BeO are present.

FUTURE OF MINING IN THE AREA

Premium payments for copper, lead, and zinc were important economic factors in encouraging production of these metals from the Bagdad area during and after World War II. Increased prices for these metals stimulated mining after the cessation of premium payments. The increased price for tungsten encouraged development of the Tungstona mine in 1952. The prices received for these metals and low costs in mining and treatment of their ores are of paramount importance in determining if mining is to continue in the future.

The mineralized rock in the vicinity of the Giroux adit (fig. 22) is rather promising ground for mixed oxidized and sulfide ores of copper; cost of treatment will determine when such mixed ore can be mined. Large tonnages of inferred low-grade primary ore around the Bagdad mine provide a major potential reserve of copper (fig. 22).

If, at some future date, there should be an expectation of continued high prices for copper and comparatively low mining costs, additional exploration might be justified in some of the mineralized breccia pipes and near the Mammoth prospect; the latter is one of the more promising copper prospects outside the main mineralized stock.

The Old Dick and Copper King mines are potential zinc producers as long as favorable prices exist. The Old Dick mine has possibilities of producing substantial tonnages of zinc, and many exploration targets are untouched. The outlook is encouraging that lower grade milling ore may be developed in sufficient tonnages at the Old Dick mine to insure continued production under favorable economic conditions.

The magnetite-ilmenite dikes in the gabbro are a potential reserve of titanium oxide when economic conditions are favorable for mining and milling of ore from deposits of the size present in the Bagdad area.

The rutile in the Bagdad ore, as indicated by available data, is about 6 pounds to the ton. Because a large tonnage is milled daily, more than 6,000,000 pounds of rutile is passing through the mill each year. The small size of the rutile crystals presents metallurgical problems in their recovery, but it should be emphasized that the Bagdad porphyry copper ore is a potential source of rutile, and metallurgical research may be justified to determine if rutile can be recovered economically.

The pegmatite dikes in the Bagdad area locally contain sufficient beryl to make beryl an important economic mineral in the future if prices are favorable and metallurgical methods are improved.

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