Geology and Ore Deposits of the Dragoon Quadrangle Cochise County, Arizona

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GEOLOGY AND ORE DEPOSITS OF THE DRAGOON QUADRANGLE, COCHISE COUNTY, ARIZONA

By John R. Cooper and Leon T. Silver

ABSTRACT

The area described in this report is in Cochise County in southeastern Arizona and comprises a little more than 250 square miles in the northwestern part of the county. The mining district known as Johnson Camp is near the center of the area, and the village of Dragoon on the Southern Pacific Railroad is near the southeastern corner.

The area is in the Mexican Highland section of the Basin and Range province and straddles the divide between the San Pedro valley on the west and the Sulphur Spring valley on the east. The Little Dragoon Mountains in the south-central part of the area constitute the principal topographic feature. In the eastern part are the north tip of the Dragoon Mountains, the Gunnison Hills, the Steele Hills, and the south tip of the Winchester Mountains. In the west-central part are the Johnny Lyon Hills, from which a ridge extends northward and joins the Galiuro Mountains north of the area described.

The rock formations of the area range in age from Precambrian to Recent. The oldest rocks are moderately metamorphosed graywackes, slates, and lava flows that make up the Pinal schist of early Precambrian age. Also early Precambrian are rhyolite porphyry intrusive sheets and stocks, a large granodiorite mass in the Johnny Lyon Hills, and granite exposed at the south end of the Winchester Mountains. The Tungsten King granite and associated aplite on the west side of the Little Dragoon Mountains, and granite exposed at the north end of the Dragoon Mountains are also referred to the early Precambrian but could be younger.

Upper Precambrian rocks, generally unmetamorphosed, include the Scanlan conglomerate, Pioneer shale, Barnes conglomerate, and Dripping Spring quartzite which are part of the Apache group; extensive diabase sills of Precambrian age were intruded into these rocks.

In slight angular discordance on the upper Precambrian formations is about 6,000 feet of Paleozoic sedimentary rocks with no angular discordances in the section. The Cambrian is represented by the Bolsa quartzite and the overlying Abrigo formation. The Upper Devonian Martin formation rests directly on the Abrigo. The Lower Mississippian Escabrosa limestone rests on the Martin and is followed by the Black Prince limestone which is doubtfully referred to the Upper Mississippian but which may be Lower Pennsylvanian. The Pennsylvanian and Permian are represented by the Naco group which is here nearly 4,000 feet thick and has been divided into 6 formations. These formations are, in ascending order, the Horquilla limestone (Middle Pennsylvanian and lower Upper Pennsylvanian), the Earp formation (Upper Pennsylvanian and lowermost Permian), and the Colina limestone, Epitaph dolomite, Scherrer formation, and Concha limestone (all Permian). The Epitaph dolomite has not been recognized north of the Dragoon Mountains.

Mesozoic rocks include the Walnut Gap volcanics, which are a locally occurring sequence of andesitic and dacitic rocks referred to the Triassic or Jurassic, and the Bisbee group of Early Cretaceous age. The Bisbee group is here divided into two units: the Glance conglomerate and the Morita and Cintura formations undivided. There are unconformities at the base of the Walnut Gap volcanics and the Bisbee group, but the angular discordanc is slight. An unnamed group of clastic sedimentary and volcani rocks, in fault relation to older rocks at the south end of the Winchester Mountains, is referred to the upper Lower Cretaceous or Upper Cretaceous. These rocks and all the older formations have been folded and thrust faulted.

The Texas Canyon quartz monzonite in the southern part of the Little Dragoon Mountains was intruded after this folding and faulting, probably in early Tertiary time. Aplite and lamprophyre dikes were intruded after the quartz monzonite was emplaced.

The Threelinks conglomerate and overlying Galiuro volcanics which crop out in the northern part of the area are of middle Tertiary age. Several rhyolite dikes in the Little Dragoon Mountains and the Johnny Lyon Hills are probably the same age as the Galiuro volcanics.

Late Tertiary and Quaternary rocks comprise stream and lake deposits equivalent to the Gila conglomerate (Pliocene and Pleistocene), younger pediment gravels, and Recent alluvium. These rocks were not studied in detail and are shown as a single formation on the geologic map.

During early Precambrian time the Pinal schist and intrusive rhyolite porphyry were deformed into close folds with axial-plane schistosity and lineation parallel to the fold axes. The general structural trend is northeast, as it is in many parts of southern Arizona. In the Johnny Lyon Hills and northern part of the Little Dragoon Mountains, the folds are commonly overturned to the northwest, and the fold axes are steep. Elsewhere the structure is more erratic and has not been deciphered in detail. The lower Precambrian granitic rocks are posttectonic.

Slight warping and probably minor faulting near the close of Precambrian time are shown by the relations of the Bolsa quartzite to the Apache group and Precambrian diabase. Steep faults, of at least two ages between Early Permian and Early Cretaceous, are truncated by unconformities at the base of the Walnut Gap volcanics and the Bisbee group.

All rocks older than the Texas Canyon quartz monzonite and the Threelinks conglomerate show the effects of a major orogeny during the Late Cretaceous or early Tertiary. The folds formed at this time trend north to northwest almost at right angles to the pre-Apache structural features. Large thrust faults on which the direction of overriding was to the northeast are exposed in the Dragoon Mountains, the southwestern part of the Little Dragoon Mountains, and the Johnny Lyon Hills.

The overridden block north of this zone of thrusts contains scarce and mostly inconspicuous thrust faults on which the indicated direction of overriding was to the west or northwest. The dominant structural feature of the block is a major tilting to the northeast. The Precambrian basement is exposed only along the southwest side of the block. Along the northeast side, at the south end of the Winchester Mountains, the basement is probably many thousand feet below the surface. The great tilted block is modified by folds trending north to northwest and by several sets of steep faults. In parts of the block in which the Paleozoic section is exposed, the folds are broad and open; but in the Morita and Cintura formations in the Steele

Hills, they are closed and locally overturned to the northeast.

The tilted block just described is bounded on the northeast, at the south end of the Winchester Mountains, by a zone of major thrust(?) and strike-slip(?) faults. North of this fault zone is a block in which the basement stands structurally high and in which lower Precambrian rocks are exposed.

The tilted block is bounded on the west, about 6 miles northwest of the Johnny Lyon Hills, by a zone of thrust faults which trend north nearly parallel to the San Pedro valley. Along this fault zone, lower Precambrian rocks of the tilted block have been thrust westward over the Walnut Gap volcanics and the Bisbee group. There are only small exposures of the fault zone northwest of the Johnny Lyon Hills and the one in the Winchester Mountains, but the structural relief in both zones is great.

Some local deformation accompanied intrusion of the Texas Canyon quartz monzonite, and further deformation in the form of gentle folding and important block faulting followed in Tertiary and early Quaternary time; this deformation outlined the basins and mountains of the present. After faulting ceased, extensive pediments were cut on the less resistant formations. These pediments are now being dissected at most places.

Carbonate rocks in the vicinity of the Texas Canyon stock have been metamorphosed and show successive zones characterized as the stock is approached, by (1) chlorite (locally talc), (2) tremolite, (3) forsterite and diopside, and (4) garnet (with local wollastonite and idocrase). The mineralogical and textural changes indicate an origin of the silicate minerals by a fixed sequence of chemical reactions between original constituents of the sedimentary rock. Only a negligible amount of material was added from an outside source, but there was considerable interchange of material between beds. Silicate minerals generally did not form in pure carbonate rocks in any of the zones. The distinctive silicates of the outer three zones formed in abundance only in impure dolomites. Garnet, wollastonite, and idocrase of zone 4 formed only in impure limestones; the mineral assemblages in the once dolomitic rocks remained the same in zone 4 as in zone 3.

The chemical reactions that can reasonably be inferred release carbon dioxide and result in the formation of denser minerals; this action suggests a decrease in volume, which stratigraphic measurements confirm—the silicated facies is as much as 30 percent thinner than the unsilicated facies. Structural features resulting from the loss in volume are obscure because of greater deformation not due to the metamorphism and because of recrystallization during the metamorphic process. To determine the gains and losses of constituents the losses in volume must be taken into account in comparing chemical analyses of unmetamorphosed and metamorphosed facies.

The entire area has been included in the Cochise mining district, a large unorganized district that has never been consistently defined. Parts of the area are commonly referred to by other names that have more definite geographic and geologic significance.

Copper and zinc deposits at Johnson Camp, which by the end of 1955 had yielded nearly 1 million tons of ore with a value of about $20 million, are much the most important deposits commercially. These deposits are northeast of the Texas Canyon quartz monzonite stock and are of the pyrometasomatic type. Metalization was preceded by thermal metamorphism which converted impure carbonate rocks to garnet, diopside, and other silicate minerals. Pyrite, sphalerite, chalcopyrite, and locally bornite have replaced favorable beds in the metamorphosed sequence near fissures and other structural features that provided channels for mineralizing solutions. The ore bodies have the form of tabular masses and chimneys in the plane of the beds. Large ore bodies, so far found, have all been within a narrow stratigraphic interval in the Abrigo formation.

Tungsten deposits, generally called the Dragoon tungsten deposits, have had a moderate production. Most of the tungsten has come from veins and lodes in the northeastern part of the stock of Texas Canyon quartz monzonite and from placers derived from these deposits. The veins trend northeast and consist of huebnerite, scheelite, and traces of base-metal sulfides in a gangue of quartz, muscovite, and fluorite. Rich ore pockets have been mined from shallow workings, but the metalized veins have proved too small and the tungsten content too erratic for profitable deep mining. At the Tungsten King mine on the west side of the Little Dragoon Mountains, scheelite ore has been mined from a contact vein between the Tungsten King granite and the Pinal schist; reported production to 1954 was about 12 tons of scheelite concentrates.

Small lead-silver vein and replacement deposits occur in the northern part of the Gunnison Hills. The richest and almost the only productive deposit is at the Texas Arizona mine, from which recorded shipments between 1908 and 1928 totaled 718 tons of ore that averaged nearly 40 percent lead and 50 ounces of silver to the ton. These ores were oxidized and occurred as small replacement bodies along beds and fissures in the Escabrosa limestone.

A little copper and tungsten ore has been shipped from deposits in the Paleozoic rocks near the Texas Canyon quartz monzonite west of Dragoon. Shipments of a few carloads of siliceous silver ore have been reported from the Winchester district in the Winchester Mountains just north of the Dragoon quadrangle, and a few unconfirmed shipments of gold have been reported from the Yellowstone district in the Johnny Lyon Hills.

Marble, in the form of rough monumental stone, terrazzo, and roof chips, is produced near Dragoon. Operations to date have been on a small scale.

INTRODUCTION

LOCATION, ACCESSIBILITY, AND CULTURE

The Dragoon quadrangle, Arizona, is bounded by the meridians 110° and 110°15′ W. and the parallels 32° and 32°15′ N., in northwestern Cochise County. It embraces an area of 253 square miles of typical "basin and range" country of southeastern Arizona about 50 miles east of Tucson and the same distance north-northwest of Bisbee. (See fig. 1.)

The main line of the Southern Pacific Railroad crosses the southeastern corner of the quadrangle; passenger, freight, and express service is available at Dragoon, a railroad village for which the quadrangle was named. An excellent paved highway, Arizona 86, crosses the quadrangle and connects with a main transcontinental highway, U.S. 80, at Benson, Ariz., and Steins, N. Mex. Most of the traffic between these points uses the route through the Dragoon quadrangle, rather than U.S. 80, which follows a longer route via Bisbee. Modern accommodations, stores, and restaurants are available at Benson and Willcox—respectively, 9 miles west and 12.5 miles east of the Dragoon quadrangle via Highway 86.

A well-graded dirt road between Willcox and Cascabel crosses the northern part of the Dragoon quadrangle,

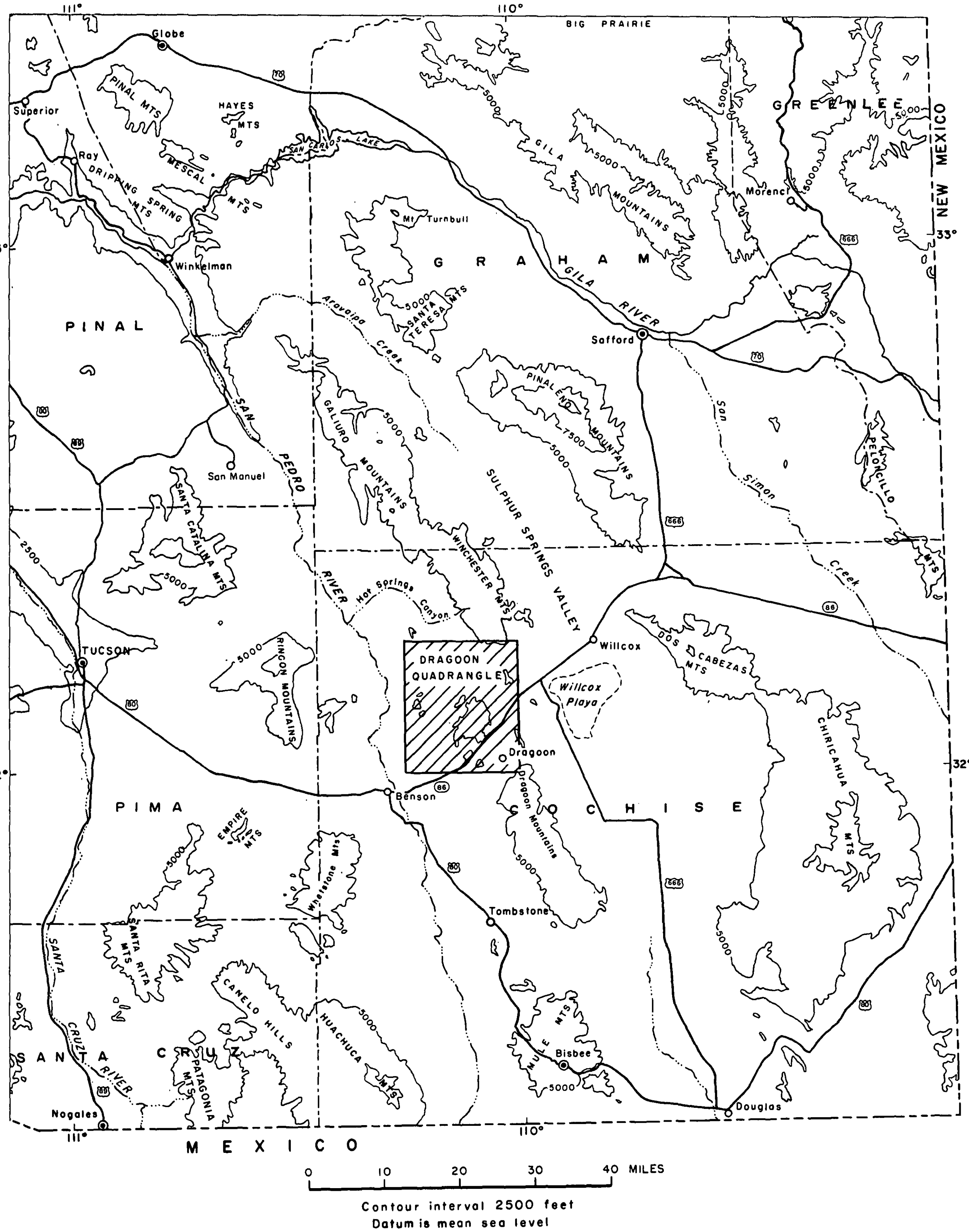

FIGURE 1.—Index map of southeastern Arizona showing the location of the Dragoon quadrangle.

and other graded roads run to all settlements and to the larger ranches. With truck or jeep it is possible to drive within several miles of any locality by following unimproved ranch roads or by driving cross country.

The area is sparsely populated. The railroad village of Dragoon has a few families, a post office, and a general store. Six miles north of Dragoon, the mining town of Johnson has grown up and disappeared several times with fluctuations in mining activity there. After more than 20 years as a ghost town, it was resurrected in 1942 by the Coronado Copper and Zinc Co. and gradually built up into a neat company town with a population of about 200, much the largest community within the quadrangle boundaries. About 2 miles southwest of Johnson, there is a cluster of dwellings known locally as Russellville. Other residents are dispersed on cattle ranches.

Practically no agricultural crops are raised because of the scarcity of water, but cattle grazing is an important and stable element in the economy. Mining started in the eighties but has not been continuous. It was important from 1942 to 1957. Copper and zinc are mined near Johnson, an area that mining men have known for many years as Johnson Camp; southwest of Johnson, tungsten is mined on a small scale from widely scattered deposits generally referred to as the Dragoon or Little Dragoon deposits; a little lead-silver ore has been mined in the past. All these deposits are in the Cochise mining district. Some marble is produced southeast of Dragoon.

PHYSICAL FEATURES

The area of this survey is in the basin and range country that extends from Nevada and western Utah southward into Mexico. More specifically it is part of what Fenneman (1931, p. 379) calls the Mexican Highland section of the Basin and Range physiographic province. This section extends north from central Mexico and forms a band 50 to 100 miles wide around the southern edge of the Colorado Plateau, which makes up a large area in northeastern Arizona, northwestern New Mexico, southeastern Utah, and southwestern Colorado. The Mexican Highland section is higher than the adjacent part of the basin and range country and has a greater proportion of the surface occupied by ranges and less by basins. Ranges make up roughly half the surface in this part of Arizona but generally less than a fifth of the surface of the southwestern part of the State.

The Dragoon quadrangle straddles the divide between two major valleys, the San Pedro valley on the west and the Sulphur Spring valley on the east. Both these valleys extend from Mexico more than 100 miles into Arizona. They trend north-northwest, and their axes are 20 to 30 miles apart. The San Pedro valley contains the only permanent stream in this part of the State—the San Pedro River, which rises in Sonora, Mexico, and flows northward and empties into the Gila River at Winkelman. The part into which the Dragoon quadrangle drains ranges in elevation from 3,200 to 3,575 feet above sea level. The Sulphur Spring valley has no through-going drainage. The part into which the Dragoon quadrangle drains is occupied by the Willcox Playa, a desert sink 4,135 feet in elevation at its lowest point.

A mountain barrier separates the San Pedro valley from the Sulphur Spring valley at most places. The Dragoon quadrangle contains Dragoon Pass, one of the lowest points in the divide (4,620 ft); this pass is on the route of the Southern Pacific Railroad and was earlier the route of the Butterfield stage. South of Dragoon Pass are the Dragoon Mountains and farther south the Mule Mountains, which continue to the Mexican border. North of the Dragoon quadrangle, the Winchester Mountains and Galiuro Mountains make up a continuous mountain range to the Gila River, about 70 miles to the north.

Within the Dragoon quadrangle the mountain barrier is broken up into small ranges and basins. The Little Dragoon Mountains in the south-central part of the quadrangle are an elliptical northward-trending mass 10½ miles long and 6 miles wide. The highest peaks, Lime Peak with an elevation of 6,726 feet and Johnson Peak with an elevation of 6,644 feet, are in the rugged northern half of the range. The southern half is made up of sharp but lower peaks and ridges with intervening broad valleys cut in quartz monzonite. This part of the range, which Highway 86 crosses via Texas Canyon, contains great monolithic outcrops and abundant pedestal rocks and balanced boulders.

East of the Little Dragoon Mountains, in the gap between the Dragoon and Winchester ranges, there are three groups of hills. In the south part of the gap are the Gunnison Hills, which extend north-northwestward for about 7 miles as a hogback ridge broken only by Walnut Gap near Highway 86. The highest point is 5,530 feet above sea level. About a mile northeast of the Gunnison Hills and a short distance east of the Dragoon quadrangle boundary, the Red Bird Hills cover several square miles and rise to an elevation of 5,079 feet. A mile and a half northwest of the Red Bird Hills and on the northern projection of the Gunnison Hills, the Steele Hills rise to 5,270 feet, with a steep slope to the Sulphur Spring valley and a gentle slope to the west.

Southwest of the Little Dragoons there is a gradual slope to the San Pedro River, but to the northwest a spur of the Galiuro Mountains intervenes. Several miles west of the Little Dragoons, at the south end of the spur, the Johnny Lyon Hills rise sharply to an elevation of 5,730 feet. North of the Johnny Lyon Hills, a lower asymmetric ridge slopes gently toward the east but breaks away sharply on the west to a rock-cut granitic plain about 500 feet lower in elevation. The ridge is breached by Kelsey Canyon near the northern boundary of the Dragoon quadrangle and again 7 miles farther north by Hot Springs Canyon near the Mule Shoe ranch.

The alluvial basins between the principal mountains and hills are in various stages of erosion. Dissection to depths of 50 to 250 feet is thorough and intricate along the middle and lower reaches of large washes tributary to the San Pedro River. The largest of these washes is Tres Alamos Wash, which rises 2½ miles northeast of Johnson and flows around the north end of the Little Dragoons and thence to the San Pedro via the gap between the Little Dragoons and the Johnny Lyon Hills. Recent dissection by this wash and by Kelsey Canyon Wash decreases rapidly in their upper reaches and leaves about 30 square miles of smooth and gently sloping plain, called Allen Flat, west of the Winchester Mountains and the Steele Hills. Southwest of the Little Dragoons the country is thoroughly dissected by Sheep Wash, Texas Canyon Wash, and Dragoon Wash.

At the east edge of Allen Flat, between the Winchester Mountains and the Steele Hills and between the Steele Hills and the Gunnison Hills, the land slopes off fairly steeply toward the Sulphur Spring valley as a result of headward erosion by short unnamed tributaries of the Willcox Playa.

CLIMATE AND VEGETATION

The climate of the region is arid, and summers are hot and winters cool. Systematic weather records are available for four localities within a few miles of the Dragoon quadrangle, namely Benson in the San Pedro valley to the west, Cochise and Willcox in the Sulphur Spring valley to the east, and Cochise Stronghold in the Dragoon Mountains to the southeast. Data for these localities according to Smith (1945, tables 2, 5, 16, 18) are given in the table that follows. These data suggest that the normal precipitation for the quadrangle is about 11 inches in the lower parts and perhaps 15 to 20 inches in the higher parts. Thunderstorms during July and August make these the wettest months. There is another rainy period from December to March. April, May, and June are very dry.

Temperatures exceeding 100°F are common during the summers; they occasionally fall as low as 0°F during the winters. The extremes of temperature are moderated by a diurnal range averaging more than 30°F. The mean annual temperature is 64.2° at Benson, 61.2° at Cochise, 60.0° at Cochise Stronghold, and 59.6° at Willcox; the Benson figure is roughly the same as that for Fort Worth, Tex., and the figure for Willcox corresponds to those for Mexico City, and Nashville, Tenn. The mild winters and dry air of the summers make year-round fieldwork possible with a minimum of discomfort.

Climatic data for stations near the Dragoon quadrangle

Location and elevation	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Extreme temperatures (°F)													
Benson, 3,585 ft	84	86	94	98	107	112	112	113	108	103	93	83	113
	5	9	13	22	22	35	46	42	35	15	9	5	5
Cochise, 4,219 ft	79	80	95	100	105	112	113	110	107	94	85	76	113
	0	10	14	21	30	38	49	48	35	21	12	—4	—4
Cochise Stronghold, 4,950 ft	75	85	89	92	105	105	104	104	99	95	90	76	105
	8	9	19	21	24	37	50	50	36	23	14	14	8
Willcox, 4,200 ft	80	89	93	95	105	109	111	108	106	99	91	82	111
	2	6	9	18	15	30	42	40	33	18	8	—2	—2
Mean maximum and mean minimum temperatures (°F)													
Benson, 3,585 ft	63.9	66.9	73.3	79.5	87.9	97.0	96.4	93.8	90.9	83.6	72.4	63.1	80.7
	28.4	32.3	36.3	41.6	48.5	57.6	65.0	63.2	56.2	44.0	34.1	29.6	44.7
Cochise, 4,219 ft	58.7	62.7	69.0	75.4	84.8	94.6	92.4	90.6	87.8	78.9	67.9	58.2	76.8
	28.7	30.2	33.2	38.7	47.8	56.7	63.7	62.6	55.5	42.3	34.0	27.7	43.4
Cochise Stronghold, 4,950 ft	57.3	61.2	67.6	75.2	84.0	92.5	91.8	88.9	86.8	79.0	66.2	57.9	75.7
	27.2	32.3	35.8	42.5	48.7	58.4	62.4	60.0	55.9	45.3	33.7	29.2	44.3
Willcox, 4,200 ft	57.6	61.8	68.3	75.9	83.6	92.7	92.6	89.6	86.5	78.4	67.1	57.8	76.0
	24.8	27.8	31.6	36.3	42.4	52.4	61.4	60.5	53.6	40.0	30.7	25.8	40.6
Normal precipitation (inches)													
Benson, 3,585 ft	0.59	0.78	0.50	0.17	0.13	0.34	2.40	2.55	1.27	0.59	0.53	0.65	10.50
Cochise, 4,219 ft	.70	.90	.68	.22	.24	.28	2.87	2.26	1.24	.58	.84	.84	11.65
Cochise Stronghold, 4,950 ft	1.06	1.61	1.15	.53	.37	.40	3.46	3.86	2.06	.83	1.18	1.70	18.21
Willcox, 4,200 ft	.82	.99	.76	.19	.25	.30	2.32	2.58	1.14	.65	.71	.91	11.62
Mean snowfall (inches)													
Benson, 3,585 ft	0.6	0.7	Tr	0	0	0	0	0	0	0	Tr	0.6	1.9
Cochise, 4,219 ft	1.1	1.2	0.4	0	0	0	0	0	0	0	0.3	1.2	4.2
Cochise Stronghold, 4,950 ft	1.6	1.5	.9	.2	Tr	0	0	0	0	0	.4	2.2	6.8
Willcox, 4,200 ft	1.3	1.1	.7	Tr	0	0	0	0	0	0	.1	1.2	5.4

The vegetation is typical of intermediate elevations of the basin and range country of Arizona. The intermountain basins and lower slopes support bunchgrasses and a considerable variety of larger plants, including the mesquite, catclaw, greasewood, yucca, Spanish-bayonet, mescal, and ocotillo, as well as the prickly pear, cholla, and several other kinds of cactus. The only large trees in the basins are cottonwoods and walnuts, which are confined to washes or other relatively moist places. At higher elevations, there are scattered live oak and juniper. A fairly dense growth of piñon pine is common on north-facing slopes in the mountains, but the elevations are not high enough for yellow pines. None of the trees or shrubs is of value for lumber or mine timber, but they are used to a limited extent for fenceposts and firewood.

PREVIOUS WORK

The published information on the Dragoon quadrangle deals largely with the copper-zinc deposits at Johnson Camp and the tungsten veins in the southern part of the quadrangle. Early mining and smelting operations at Johnson were mentioned by Hamilton (1883, p. 87), but no geologic data were given. Several decades later Kellogg (1906) published a brief description of the geology near Johnson, including a small-scale sketch map. He recognized schist (Pinal schist and parts of the Apache group), quartzite (Bolsa and Dripping Spring quartzites), limestone (Abrigo and overlying formations), and granite (Texas Canyon quartz monzonite). He also noted the presence of contact silicates in the lower part of the limestone, quartz-tungsten veins in the granite, and barren or rarely cupriferous quartz veins in the other rocks. The uplift of the Little Dragoons including all folds and faults, the metamorphism, and the ore formation were attributed to the intrusion of the granite which was regarded as corresponding to the granite porphyry at Bisbee. The tungsten veins were interpreted as very silicic pegmatites, and the copper deposits as contact metamorphic deposits. He recognized that the copper ore bodies were localized along bedding planes and that the main ore minerals are chalcopyrite, sphalerite, and bornite. The molybdenite in these deposits was reported by Guild (1910, p. 24), and scheelite was first recognized by Larsen (Hess and Larsen, 1922, p. 260). Reports by Dinsmore (1909) and Scott (1916) give historical information on mining and a little geologic information.

Several brief reports on the Johnson Camp area have appeared in recent years. An account entitled "Coronado's Republic mine" appeared in the Mining World for August 1946 and gives the background and many details of recent mining and milling operations. Other reports include a summary of the results of an exploratory drilling project on the Keystone and St. George properties by the U.S. Bureau of mines (Romslo, 1949), a preliminary summary of the geology of the district (Cooper, 1950), a description of a geochemical prospecting experiment (Cooper and Huff, 1951), and discussions of the localization of the ores (Arthur Baker, 1953) and metamorphism of the carbonate rocks (Cooper, 1957).

Blake (1898, 1899) reported the discovery of tungsten in quartz veins near Russellville and gave a brief description of the occurrence. Some additional information on the deposits and on mining operations was given by Rickard (1904), Richards (1908), and Scott (1916, p. 143). A brief but excellent summary of the geology of the deposits was given by Wilson (1941, p. 41–45) in his report on the tungsten deposits of Arizona.

The first work specifically directed toward the general geology was by N. H. Darton, who included the Dragoon quadrangle in his area of reconnaissance for the geologic map of Arizona published in 1924 (Darton and others, 1924; Darton, 1925, p. 297; 1933, p. 158–160, map sheet 21). He noted the presence and character of the principal Paleozoic formations and recorded their general areal distribution. Subsequently the geology faculty and students of the University of Arizona made field studies in the area from time to time. Prof. A. A. Stoyanow (1936, 1942) incorporated some of this work in his discussions on the Paleozoic stratigraphy and paleogeography of Arizona, and H. E. Enlows (1941) published a short description with geologic map of the northeastern part of the Little Dragoons. Unpublished theses by students, available in manuscript form at the University library in Tucson, include reports by R. E. S. Heineman [1] on the area near Johnson, F. S. Cook [2] on the Seven Dash Ranch area, and H. E. Enlows [3] on the geology of the northeastern part of the Little Dragoons. Heineman established the post-Carboniferous age of the Texas Canyon stock, noted the abundance of orthoclase in the rocks and ores at Johnson, and pointed out the importance of cross fractures as well as beds in localizing the ore bodies. Cook and Enlows recognized and mapped the Apache group in the northeastern part of the Little Dragoons as well as many post-Paleozoic structural features, including remnants of thrust plates near the summit of the range. The work of Cook and Enlows is combined in the summary by Enlows (1941). A report on the late Paleozoic stratigraphy of central Cochise County (Gilluly and

[1] Heineman, R. E. S., 1927, The geology and ore deposits of the Johnson mining district, Arizona: Arizona Univ. M.S. thesis (on file at Arizona Univ. Library), 45 p., map.

[2] Cook, F. S., 1938, The geology of the Seven Dash Ranch area, Cochise County, Arizona: Arizona Univ. M.S. thesis (on file at Arizona Univ. Library), 26 p., maps.

[3] Enlows, H. E., 1939, Geology and ore deposits of the Little Dragoon Mountains: Arizona Univ. thesis (on file at Arizona Univ. Library), 41 p., map.

others, 1954) summarized many of our data on the Mississippian, Pennsylvanian, and Permian rocks, as well as data obtained by James Gilluly in mapping the area between the Dragoon quadrangle and the Bisbee district.

Parts of the Dragoon quadrangle are described in several U.S. Geological Survey reports on ground-water geology. These reports, by Meinzer and Kelton (1913), Jones and Cushman (1947), and D. R. Coates (Halpenny and others, 1952, p. 177–186) on the Sulphur Spring valley, and by Bryan, Smith, and Waring (1934), and L. A. Heindl (Halpenny and others; 1952, p. 69–100) on the San Pedro valley, deal mostly with the alluvial basins and their margins. Our mapping of the bedrock geology of the Dragoon quadrangle was available to the authors of the reports released after 1946, but the interpretation is in part their own.

FIELDWORK AND ACKNOWLEDGMENTS

This report seeks to synthesize and supplement the information in the reports just mentioned and to give a detailed account of the areal and economic geology. The purpose more broadly viewed is to contribute to an understanding of the geology of southeastern Arizona, which has been a major source of copper and an important source of other base metals.

Fieldwork began in April 1944 and after many interruptions was completed in September 1953. J. R. Cooper, who had charge of the work from its inception, spent about 43 months in fieldwork. L. T. Silver, who joined the project in June 1949 and carried on the fieldwork independently during the summers of 1950 and 1951, spent about 12 months in the field. T. W. Amsden, F. W. Farwell, Kuo Wen Kwei, F. G. Bonorino, A. E. Disbrow, Jules A. MacKallor and C. T. Wrucke assisted in the survey at various times. We are indebted to these assistants for much of the mapping, as well as for stimulating discussion of the geologic problems. In addition to mapping, Amsden did much careful work on the Paleozoic stratigraphy, and Wrucke did much careful and discriminating work in compiling maps and other illustrations.

The surface maps were made with planetable and open-sight or telescopic alidade, and the mine maps were made with Brunton and tape. Large-scale planetable maps were made in the vicinity of some of the mines and at a few other places where detail was needed to clarify the geologic relations. Cooper and Silver have collaborated since 1949; Silver is mainly responsible for the mapping and interpretations of the Johnny Lyon Hills and the area north of them, and Cooper is mainly responsible for the mapping and interpretations in the rest of the quadrangle.

We are greatly indebted to the management and staff of the Coronado Copper and Zinc Co., who permitted access to the company mines at Johnson and made pertinent records of the company freely available. Our maps of the Moore mine and the deepest part of the Republic mine, which were opened after our mine mapping was done, are taken with only very slight modifications from excellent maps by Arthur Baker 3d, formerly geologist of the company. Dr. S. C. Hu, president of the Standard Tungsten Corp., has furnished maps showing recent workings in the Tungsten King mine; and Dr. E. D. Wilson, geologist of the Arizona Bureau of Mines, has permitted us to use his geologic maps of the O. K. and Keystone (Hagerman) mines.

We are also indebted to many professional colleagues both inside and outside the Geological Survey for field discussions of geologic problems, for chemical and spectrographic analyses, and for identification and interpretation of fossils and minerals. Specific acknowledgments are made where appropriate in the body of the text. The facilities of the geochemical laboratories at the California Institute of Technology, Pasadena, Calif., were available for mineral separations and analyses by chemical and mass-spectrographic techniques.

GEOLOGIC FORMATIONS

GENERAL FEATURES

The rocks of the Dragoon quadrangle range in age from Precambrian to Recent and constitute a wide variety of lithologic types. A lower Precambrian complex of folded metasedimentary and metavolcanic rocks cut by igneous intrusions is overlain locally by as much as 500 feet of upper Precambrian conglomerate, shale, and quartzite cut by diabase sills. In unconformable but nearly concordant contact on the upper Precambrian rocks is about 6,000 feet of Paleozoic sedimentary rocks in which the Ordovician and Silurian are the only systems unrepresented. Mesozoic rocks, separated from the Paleozoic section by an important unconformity, include locally occurring volcanic tuff, breccia, and conglomerate probably of Triassic or Jurassic age, followed in unconformable relation by at least 3,000 feet of Lower Cretaceous conglomerate, sandstone, shale, and subordinate limestone. A younger series of feldspathic sandstone, siltstone, and conglomerate grading upward into andesitic tuff and breccia of Cretaceous or possibly early Tertiary age is exposed in fault contact with the Paleozoic rocks. Following a major orogeny, a large stock of quartz monzonite and later aplite and lamprophyre dikes were intruded, presumably in early Tertiary time. Conglomerate of Tertiary age lies with angular unconformity on the Cretaceous rocks and underlies and interfingers(?) with the lower part of a volcanic series ranging in composition from basaltic andesite to rhyolite. A few late rhyolite dikes are probably related genetically to the volcanic rocks. Unconsolidated to semiconsolidated alluvium and lake deposits of late Tertiary to Recent age are the youngest deposits of the area.

Our map units and some of their general characteristics are summarized in the following table. The succeeding pages give detailed discussions of each, in the order of age insofar as possible.

Rock formations in the Dragoon quadrangle

Age		Group, formation, and member		Lithology and remarks	Thickness (feet)
Quaternary	Pleistocene and Recent	Alluvium		Conglomerate, sand, and fine-grained lake deposits; unconsolidated to semiconsolidated. Older part equivalent to Gila conglomerate.	0–600+
Tertiary	Pliocene				
		Unconformity			
Tertiary	Paleocene(?) to lower Pliocene(?)	Rhyolite dikes		Rhyolite, gray to red-purple, commonly flow banded; small phenocrysts of quartz and sanidine. Probably same age as Galiuro volcanics.	
		Intrusive contact			
		Galiuro volcanics	Rhyolite member	Rhyolite, welded tuff, crystal tuff, and flows(?); porous vitric tuff generally at base. Lies directly on Threelinks conglomerate in Steele Hills.	900
			Unconformity		
			Conglomerate member	Volcanic conglomerate with subordinate sandstone, tuff and pyroclastic breccia. Found in Kelsey Canyon only.	500
			Unconformity		
			Latite member	Latite flows, gray to purple; underlain in Winchester Mountains by a cliff-forming pink rhyolitic welded tuff.	300+
			Basaltic andesite member	Basaltic andesite flows and subordinate tuff-breccia, characterized by plagioclase phenocrysts 1 to 2 in. long.	450
		Threelinks conglomerate		Conglomerate, bouldery, partly consolidated; intercalated with soft sandstone, siltstone, basalt and andesite flows, and quartz-latite pyroclastic rocks. Probably intertongues with lower units of Galiuro volcanics.	50–2,000(?)
		Unconformity			
Tertiary(?)		Lamprophyre dikes		Dark igneous rock; occurs as dikes, sills, and few small plugs.	
		Intrusive contact			
		Aplite		Aplite; grades to alaskite and pegmatite; occurs as dikes and irregular intrusive bodies in and near the Texas Canyon quartz monzonite.	
		Intrusive contact			
		Texas Canyon quartz monzonite		Biotite-quartz monzonite, medium-grained; commonly contains phenocrysts of potassic feldspar an inch or two in length.	
		Intrusive contact			
Cretaceous(?)	Lower (?) or Upper (?)	Unnamed sedimentary and volcanic rocks		Feldspathic sandstone, siltstone, and conglomerate; grades upward into andesitic tuff and breccia.	4, 900(?)
		Fault contact			

Rock formations in the Dragoon quadrangle—Continued

Age			Group, formation, and member			Lithology and remarks	Thickness (feet)
Cretaceous		Lower (Comanche)	Bisbee group	Morita and Cintura formations undivided		Interbedded sandstone, quartzite, and shale, with scarce thin limestone units and at least one bed of conglomerate resembling the Glance in lithology. Contact with Glance conglomerate not exposed.	2, 500+
				Glance conglomerate		Limestone conglomerate characterized by closely packed cobbles, tightly cemented.	500+
			Unconformity				
Triassic or Jurassic			Walnut Gap volcanics			Andesitic and dacitic tuff, pyroclastic breccia, and conglomerate. Occurs locally beneath the Glance conglomerate.	0–500+
			Unconformity				
Permian			Naco group	Concha limestone		Limestone, gray; contains many irregular chert nodules. Fossils abundant, particularly a large productid brachiopod, *Dictyoclostus ivesi bassi* (McKee).	130
				Scherrer formation		Quartzitic sandstone with basal member of red siltstone and middle member of fine-grained gray limestone. Echinoid spines abundant in the limestone.	690
				Epitaph dolomite		Dolomite, gray, fine-grained; contains small nodules of silica. Known only in the Dragoon Mountains, where it is overlain by the Glance conglomerate.	0–150(?)
				Colina limestone		Limestone, dark-gray to black; contains a few thin beds of sandstone and light-gray dolomitic limestone. Both top and bottom exposed in the Gunnison Hills, but no single section is complete.	440+
				Earp formation	Upper member	Limestone, characteristically dark-gray to black; contains abundant interbeds of sandstone and marl. Intraformational conglomerate at base. Total thickness 350 ft.	1, 130
Carboniferous	Pennsylvanian	Upper			Lower member	Limestone, characteristically light-gray to pink; contains abundant interbeds of sandstone, siltstone, and marl. Fossils, particularly fusulinids, indicate the Pennsylvanian-Permian (Wolfcamp) boundary is within this member. Total thickness 780 ft.	
		Lower		Horquilla limestone		Limestone, characteristically blue-gray, medium-bedded, and fossiliferous; thin interbeds of shale throughout; a few sandstone beds in upper part; 30 to 65 ft of red shale at base.	1, 600
	Mississippian (?) or Pennsylvanian(?)		Black Prince limestone			Limestone, pinkish-gray, thin- to thick-bedded; 10 to 30 ft of shale and chert conglomerate at base.	120–170
	Mississippian	Lower	Escabrosa limestone			Limestone, gray, thick-bedded, commonly crinoidal; about 150 ft of dolomite at base and a few beds of dolomite in middle and upper parts. Chert nodules common.	585–750

Rock formations in the Dragoon quadrangle—Continued

Age		Group, formation, and member		Lithology and remarks	Thickness (feet)
Devonian	Upper	Martin formation		Dolomite, gray to tan, fine- to medium-grained, thin-bedded; contains sandy and silty beds in lower half and 15 to 30 ft of reddish-brown shale at top.	210–270
		—Disconformity—			
Cambrian	Upper	Abrigo formation	Upper member	Sandy dolomite and dolomitic sandstone; contains few thin quartzite beds. Grades to limestone facies in northwestern part of quadrangle. Total thickness 85 to 155 ft.	700–800
Cambrian	Upper	Abrigo formation	Middle member	Limestone, gray, thin-bedded; contains abundant mostly irregular partings of silt and sand, some limy sandstone beds, and numerous intraformational limestone conglomerate beds. Total thickness 175 to 255 ft.	
Cambrian	Middle	Abrigo formation	Lower member	Shale, olive, fissile; contains a few thin beds of sandstone and dolomite in lower part, and common gray limestone units in upper part; capped by a tongue of crossbedded quartzite in northwestern part of quadrangle. Total thickness 300 to 475 ft.	
Cambrian	Middle	Bolsa quartzite		Quartzite, white to purple or brown, medium- to coarse-grained, in part pebbly; commonly contains conglomerate at base.	20(?)–480
		—Unconformity—			
Precambrian	Upper	Diabase sills		Diabase, gray-green, weathering brown, altered. Forms extensive sills at and near top of Pioneer shale.	
		—Intrusive contact—			
Precambrian	Upper	Apache group	Dripping Spring quartzite	Quartzite, pink, arkosic, fine- to medium-grained, with color and grain-size banding.	300
Precambrian	Upper	Apache group	Barnes conglomerate	Conglomerate characterized by well-rounded pebbles of quartzite and jasper, 3 to 15 ft thick, in places underlain by 1 to 50 ft of quartzite like Dripping Spring.	3–60
Precambrian	Upper	Apache group	Pioneer shale	Siltstone, purple, thin-bedded with purple sandstone or gray quartzite at base.	150–300
Precambrian	Upper	Apache group	Scanlan conglomerate	Conglomerate made up of subangular fragments in a sandy matrix. Commonly has interbeds of sandstone or quartzite.	0–30
		—Unconformity—			
Precambrian		Aplite		Sugary-textured white rock occurring as dikes and irregular intrusive bodies in the Tungsten King granite and adjacent Pinal schist.	
		—Intrusive contact—			
Precambrian		Tungsten King granite		Biotite granite, medium- to coarse-grained; has intruded the Pinal schist on west side of Little Dragoons, at north end of Dragoon Mountains, and in Winchester Mountains. The mass in the Winchester Mountains is certainly Precambrian; the others could be younger.	
		—Intrusive contact—			

Rock formations in the Dragoon quadrangle—Continued

Age		Group, formation, and member	Lithology and remarks	Thickness (feet)
	Lower	Johnny Lyon granodiorite	Hornblende-biotite granodiorite, medium- to coarse-grained; intrusive into Pinal schist and overlain unconformably by Scanlan conglomerate.	
		— Intrusive contact —		
		Intrusive rhyolite porphyry	Rhyolite of two generations: stocks and narrow sheets that intruded Pinal schist before its metamorphism; and petrographically different rhyolite sheets intruded after the metamorphism but probably still in early Precambrian time.	
		— Intrusive contact —		
		Pinal schist	Schists and slates derived from graywacke, shale, siltstone, and minor small lenses of conglomerate. Contains at least one rhyolite flow, lenses of amphibolite and chlorite schist propably derived from basic volcanic rock, and scarce other rock types of undetermined origin.	20,000(?)

LOWER PRECAMBRIAN ROCKS

PINAL SCHIST

Ransome (1903, p. 23) applied the name Pinal schists to the crystalline schists of the Pinal Mountains south of Globe. Later he (Ransome, 1904, p. 24) extended the name into the Bisbee district as Pinal schist. In this latter form the name has come into general use in southeastern Arizona. In the type locality, the formation was described as laminated gray sericitic schist with interbedded quartzose grits of sedimentary origin and a little amphibolite-schist representing basic eruptive rocks. They are strongly foliated approximately parallel to the bedding, nearly vertical in dip, and intricately intruded by granitic bodies. These rocks constitute the crystalline basement on which the Apache group was unconformably deposited.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Pinal schist crops out at many places in the southwestern half of the Dragoon quadrangle (pls. 1, 2). The northernmost outcrop is near the west edge of the quadrangle about 1½ miles north of the Willcox-Cascabel road, in a narrow thrust slice between Johnny Lyon granodiorite on the east and Walnut Gap volcanics on the west. About 3½ miles to the southeast and 2,000 feet south of the Cascabel road, the schist again appears in unfaulted position between Johnny Lyon granodiorite on the west and the Apache group on the east. From this point southward, the schist is continuously exposed in an ever-widening belt as far as the Johnny Lyon Hills, a distance of about 5 miles. Beyond this the continuity and regularity of outcrop are broken by great overthrust sheets of Precambrian and Paleozoic rocks and by overlapping alluvium. Large areas of schist are exposed in several of the thrust sheets, and small fault slices are found along the major thrusts. Southwest of Keith Ranch, an irregular but continuous outcrop extends for a few miles to the quadrangle boundary. In the marginal parts of the adjacent Johnny Lyon granodiorite, there are inclusions of schist as much as 1,500 feet long and 500 feet wide. Erosion windows in the alluvium provide small isolated outcrops as far southeast as the south boundary of T. 15 S. in Tres Alamos Wash.

In the Little Dragoon Mountains the schist is exposed over a total of about 10 square miles northwest of the Texas Canyon quartz monzonite stock. This area of outcrop is bounded on the northeast by upper Precambrian and Paleozoic rocks that form the northern and northeastern flanks of the range. The western boundary is made by overlapping alluvium, downfaulted upper Precambrian and Paleozoic sedimentary rocks, and post-Pinal igneous intrusions. Within the area thus defined, the outcrop pattern of the schist is complex and not everywhere continuous because of infolded and infaulted sedimentary rocks, igneous intrusive rocks, and patches of alluvium.

There are a few small outcrops of the schist in the southeastern half of the Little Dragoons. There are a few very small inclusions in the Texas Canyon quartz monzonite near its contact with the Pinal in the upper part of Sheep Basin and in Walnut Basin. Other exposures in the southern part of the range comprise half a dozen outcrops near the Johnson-Dragoon road between the Keystone mine and the Centurion mine;

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and some inclusions and roof pendants in the quartz monzonite about 2 miles southeast of Adams Peak.

In the Dragoon Mountains the schist crops out in a north-south belt about 2,000 feet wide between granite on the west and Bolsa quartzite on the east. No outcrops of the schist are found in the Gunnison Hills, Steele Hills, or the parts of the Winchester Mountains within the Dragoon quadrangle. Several miles north of the quadrangle boundary, the schist crops out again beneath the Galiuro volcanics of the Winchester Mountains.

In all its exposures the Pinal schist is less resistant to erosion than most of the upper Precambrian and Paleozoic sedimentary rocks. As a result, hills and ridges of schist are commonly bordered and dominated by conspicuous peaks and escarpments supported by the Bolsa quartzite, Escabrosa limestone, and other resistant formations. The schist is, however, resistant enough to be well exposed at most places and is definitely more resistant than the granitic igneous rocks. The contact-metamorphosed schist adjacent to the granitic bodies is generally more resistant than the rest of the schist and forms some prominent escarpments, as along the northwestern side of the Texas Canyon stock.

LITHOLOGY

The Pinal schist in the Dragoon quadrangle consists of a great thickness of metamorphosed sedimentary rocks containing at least one metarhyolite lava flow and a few lenses of amphibolite and chlorite schist believed to represent basaltic flows. In earlier Precambrian time these rocks were intensely deformed and were affected by a pervasive dynamothermal metamorphism generally of low rank. Later granitic intrusions ranging in age from earlier Precambrian to Tertiary have transformed inclusions and the adjacent schist to contact hornfels. During Late Cretaceous or early Tertiary orogeny, the old structural features were modified, and the schist was sheared, locally to cataclastic phases.

Despite several stages of metamorphism, the metasedimentary rocks at many places retain enough original features to indicate that they represent clastic sediments derived from terranes rich in volcanic rocks but containing also quartzites, slates and probably granitic rocks. The most prevalent sedimentary facies, shown as interbedded sericite schist and metagraywacke on the geologic map, was characterized by impure flaggy sandstone of the graywacke type, interbedded with siltstone and shale in monotonous cyclic repetition. These rocks are uniformly well bedded, with individual beds ranging from 0 to about 4 feet in thickness. Graded bedding is common. Locally, the cyclic units grade laterally into massive thick-bedded sandstone, without shale interbeds, or into shale, free of sandstone. These sandstone or shale units are 10 to 100 feet thick. Rather uncommonly, sandstone units grade into pebble and granule conglomerate. The conglomerate is largely devoid of bedding and forms lenses a few inches to 75 feet thick. The lenses seldom extend more than a few hundred feet laterally without grading into sandstone.

The main sedimentary facies, briefly described above, lacks marker beds or mappable members because of the repetitious, small-scale interfingering of lithologic types; but in the northern part of the Little Dragoons, there are mappable bodies of each of the principal lithologic types, namely shale free from coarse clastic material and sandstone which contains conglomerate lenses but only scarce, thin interbeds of shale. These units, mapped as sericite schist and metagraywacke, respectively, are like their counterparts in the main facies in every respect except size, and therefore they will not be described separately in the following detailed discussion, which is organized according to original rock type.

METAMORPHOSED CONGLOMERATES

The coarsest clastic rocks are scarce small-pebble and granule conglomerates which grade laterally into sandstone within short distances. Bedding is poorly developed, and foliation is moderate, weak, or absent.

The conglomerates are gray to dark gray and poorly sorted. The larger fragments, which make up as much as 75 percent of the rock by volume, range from 2 mm to 30 mm in major diameter. Pebbles that retain their original clastic form are subrounded to rounded and commonly ellipsoidal. Some fragments of slate and other incompetent rocks have been strongly flattened by shearing during metamorphism.

The composition of the pebbles is diverse. Volcanic rock, quartzite, and slate or phyllite are the most abundant rock types represented. Rounded individual grains of quartz, chert, and feldspar as much as 8 mm in diameter are common. Grains with well-developed micrographic intergrowths of quartz and potassic feldspar are uncommon but recurrent in thin section. A few grains show coarse quartz and plagioclase intergrowths strongly resembling granitic texture. Unfortunately none of the latter grains is large enough to be interpreted unequivocally.

The quartzite fragments range from monomineralic quartzite to sericitic quartzite transitional to quartz sericite schist. Fragments of slate, phyllite, and mica schist appear in the same specimens. The volcanic fragments are mostly silicic types with common phenocrysts of quartz and plagioclase in a fine-grained recrystallized groundmass of quartz, albite, and sericite. Many are similar lithologically to rhyolite lava interbedded with the Pinal. A few basic volcanic fragments, now consisting of chlorite-biotite-quartz-albite assemblages, were noted in thin sections from the Johnny Lyon Hills area; and abundant partly epidotized fragments are the principal coarse constituent of a conglomerate adjacent to a metabasalt band about a mile southeast of Lime Peak.

The matrix of the conglomerate is an intergrowth of quartz, feldspar, sericite, chlorite, biotite, epidote, and opaque minerals similar in general composition to the sandstone and siltstone phases of the schist.

Effects of metamorphism are evident in most specimens. The least competent fragments are flattened and stretched, and some of the quartz and quartzite fragments have granulated tails. Some fragments of fine-grained volcanic rocks are reconstituted mineralogically. The matrix is recrystallized and generally foliated. The products of recrystallization include albite and orientated micaceous minerals. Minor shear surfaces marked by concentrations of sericite, chlorite, and opaque grains parallel the foliation but rarely cut the larger fragments.

METAMORPHOSED SANDSTONES

The typical metamorphosed sandstone is a light gray to dark greenish-gray compact and tough rock in which sand grains and scarce granules of quartz, feldspar, and various types of rocks are discernible megascopically, in a finer grained matrix. The weathered surface is commonly light to dark brown. Poor sorting, common graded bedding, and sparse internal foliation are typical. Hand specimens from the top or bottom of a bed are veneered by slate or phyllite from the adjacent bed.

Microscopic examination reveals that in the sand-and-granule fraction quartz grains are generally the most abundant and followed in abundance by albite and sodic oligoclase, rock fragments, microcline, perthite, and opaque minerals. The lithic fragments are of the same rocks found in the conglomerates. The grains are mostly angular to subangular, but some are well rounded. The grain size ranges from 1/16 to 4 mm and commonly extends over all or a large part of this range in a single bed. Vertical gradation in the size and abundance of the coarser grains within many individual beds provides excellent graded bedding by which the original top and bottom can be distinguished. In the better preserved rocks, the present size and shape of the sand grains appear to be mostly original, although some grains have been slightly recrystallized or replaced on the edges (fig. 2). The grains have a slight tendency to have their long axes parallel to the bedding but only to a degree probably compatible with sedimentational orientation.

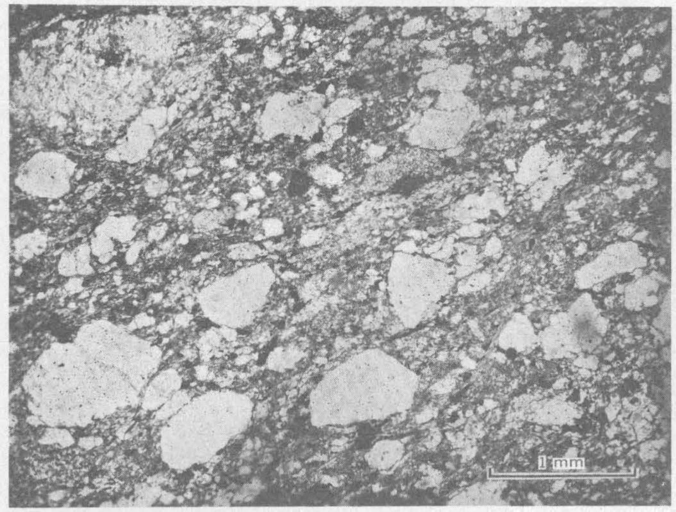

FIGURE 2.—Photomicrograph of graywacke from the Pinal schist showing characteristic sedimentary texture despite some shearing. Plane polarized light. × 20

The matrix material is completely gradational in size from fine silt to sand and may be so abundant as to isolate individual sand grains (fig. 2). It is made up of all the minerals found as coarser grains, plus sericite, chlorite, biotite, minerals of the epidote group, calcite, leucoxene, and limonite, as well as sparse amounts of such accessory minerals as apatite, zircon, tourmaline, and rutile. Fine-grained stilpnomelane(?) is present in some of the rocks. Because of its original argillic composition, the matrix has been more sensitive to metamorphism than the coarser grains. Recrystallization and reconstitution have produced a dense interlocking texture. Some of the finer grained sericite has lower indices and birefringence than normal muscovite and is probably illitic. The sericite, chlorite, and biotite are in flakes weakly to strongly oriented parallel to the schistosity and are associated with granoblastic quartz and feldspar. Magnetite with idioblastic outlines is localized in the vicinity of aggregates of biotite and chlorite.

Estimates of the mineral composition of the sandstone, maximum grain size, and volume percent of matrix material may be summarized as follows:

	Common type (16 thin sections)	Scarce and extreme types	
		Quartzitic (2 thin sections)	Tuffaceous(?) (2 thin sections)
	Percent	*Percent*	*Percent*
Quartz	40–50	85–90	25–35
Albite and sodic oligoclase (partly sericitized)	5–20	Trace	45–55
Potassium feldspar	0–5		----
Sericite	20–40	5–7	5–10
Chlorite and (or) biotite	6–12	1–5	3–5
Opaque minerals	3–5	1–5	1–3
Other minerals	1–2	Trace	1–4
Rock fragments	0–25	----	1–5
Maximum grain size mm	4	4	2
Percent matrix (<0.05 mm)	35–75	20	10–30

Precise determinations of mineral composition are limited by the difficulty of analyzing the abundant fine-grained matrix material. Excluding the tuffaceous(?) type, the higher the ratio of sand grains to matrix the higher are the ratios of quartz to feldspar, quartz to sericite, and rounded and subrounded grains to subangular and angular grains. This suggests that the scarce quartzitic sandstone beds represent locally reworked deposits in channels or elsewhere. They contain some of the rare crossbedding found in the Pinal schist. The tuffaceous(?) beds are low in matrix material but high in feldspar. The grains are subangular to angular and poorly sorted. The resemblance to crystal tuff is marked. The composition is probably not greatly different from the rhyolite lava flow described later.

Some units of uncertain origin, possibly metamorphosed vitric tuffs of silicic composition, are found in Sheep and Walnut basins. These units are included with the interbedded sericite schist and matagraywacke on the geologic map but are excluded from the foregoing table. The characteristic rock of the units is gray, aphanitic, hard, with internal foliation inconspicuous and bedding weak or absent. The units form lenses, some of which are irregular in detail and interfinger with the normal metasedimentary rocks. The largest body, a mile south of Lime Peak, is an irregular lens about 2,500 feet long and more than 700 feet wide at one place. Other smaller bodies are fairly abundant from the SE¼ sec. 28, T. 15 S., R. 22 E., to the NW¼ sec. 5, T. 16 S., R. 22 E. The typical rock from all the masses resembles the groundmass of the rhyolite lava but contains no recognizable phenocrysts of quartz and plagioclase so characteristic of that rock. A very fine grained thoroughly recrystallized texture is evident in thin section. Quartz, alkalic feldspar, and sericite are the principal minerals but are in such small crystals that their relative abundance could not be determined microscopically.

In the sandstone the dynamic effects of metamorphism are more apparent than are the thermal effects. Fairly commonly, the large sand grains are elongated parallel to the foliation and display mortared rims and tails, as well as internal granulation, and microfaulting. These effects tend to increase the apparent proportion of the matrix, for the growth by recrystallization of the fine grains does not compensate for the concurrent mechanical reduction of the coarse grains. The resulting rocks have been called semischist (Williams and others, 1955, p. 205, 216). Extreme granulation and recrystallization are characteristic of those sandstone beds which were interbedded with argillaceous material and disrupted into boudins.

Within the matrix the effects of increasing regional metamorphism involve recrystallization of the quartz and growth of sericite, chlorite, biotite, and albite. The chlorite appears both as a precursor and as a retrogressive successor of the biotite. The biotite is fine grained, in ragged flakes as much as 0.4 mm in diameter. It is pleochroic in pale yellow (X) to golden olive-brown (Y, Z). It commonly appears to have grown around magnetite grains. All the micaceous minerals assume a strong parallel orientation in the more deformed rocks. The metamorphic albite is generally fine grained but may be as coarse as 1 to 2 mm. It is full of inclusions of sericite and quartz.

In summarizing the lithologic characteristics of the better preserved sandstone in the Pinal schist, it may be said that typically it is a gray well-indurated medium and fine-grained clastic rock composed of mineral and rock fragments in an abundant argillaceous matrix, poorly sorted in grain size and commonly vertically graded in texture. The general name graywacke is applied to this rock solely on the basis of these physical characteristics.

Chemical analyses have been made of two graywacke beds, both of which display excellent graded bedding but contain slightly more quartz, less feldspar, and less matrix than the average. The analyses, with mineralogical and textural data, are given in the following table, together with average graywacke and subgraywacke analyses from the literature.

Analyses of graywacke and subgraywacke

	Graywackes from Pinal schist (SW¼ sec. 10, T. 15 S., R. 21 E.) W. J. Blake, analyst, 1953		Average of 30 graywackes (Tyrrell, 1933, p. 26)	Average of 3 subgraywackes (Pettijohn, 1949, p. 256)
Chemical analyses				
SiO_2	75.09	79.53	68.1	77.8
TiO_2	.58	.57	.7	.6
Al_2O_3	11.36	9.91	15.4	9.5
Fe_2O_3	3.11	3.26	.3(?)	.9
FeO	.94	.71	3.4	2.6
MgO	1.03	.69	1.8	1.6
CaO	1.26	.38	2.3	1.2
Na_2O	2.64	1.52	2.6	2.0
K_2O	1.86	2.25	2.2	1.5
H_2O+	1.46	1.16	2.1	1.6
H_2O-	.26	.13		.1
P_2O_5	.08	.08	.2	----------
MnO	.09	.06	.2	.2
Total	99.76	100.25	99.3(?)	99.6
Modal analyses				
Quartz	43	46		
Albite and sodic oligoclase	5	6		
Potassium feldspar	----------	1		
Sericite	38	34		
Chlorite and biotite	8	9		
Epidote	----------	1		
Ore minerals	5	4		
Others	.3	.1		
Total	99.3	101.1		
Textural analyses				
Maximum grain size mm	½	4		
Percent matrix finer than 0.05 mm	50	40		

The modal analyses were made by point-counter technique (Chayes, 1949). The limitations placed on any quantitative petrographic technique by samples which contain abundant grains less than 50 microns in diameter are in effect here. It is considered that these modes are biased so as to emphasize the colored and more birefringent micaceous minerals over the less conspicuous quartz and feldspar. Some indication of this is obtained by recalculating the Na_2O content of sample 1 to equivalent albite. The 2.64 percent of Na_2O is equivalent to more than 22 percent albite molecule, but only 5 percent feldspar is recognized in the modal analysis. A paragonitic sericite may be responsible for part of or all this discrepancy, but it is probable that some albite in the matrix is too fine grained to be recognized.

The two Pinal schist specimens are more similar in chemical composition to the average subgraywacke of Pettijohn than the average graywacke of Tyrrell. Unfortunately, no comparison of even approximate modal analyses can be made. The technical difficulties of measuring modes have undoubtedly repressed publication of pairs of chemical and mineral analyses with accompanying textural data. Until such information can be obtained, the complete significance of chemical analyses for materials classified according to texture or mineralogy is not clear. For example, it is readily calculated that many sandstones which would qualify mineralogically and texturally as Krynine's (1948, table 3) high-rank graywacke or Pettijohn's graywacke (that is, containing more than 10 percent feldspar) have a a chemical composition similar to the average "subgraywacke" given here. A hypothetical mode and a calculated chemical equivalent to illustrate this point are as follows:

Hypothetical mode		Equivalent chemical composition (calculated)	
	Percent		*Percent*
Quartz	60	SiO_2	78.9
Plagioclase (An_{13})	15	TiO_2	1.0
Muscovite	15	Al_2O_3	10.2
Chlorite	5	Fe_2O_3	.7
Magnetite	2	FeO	2.6
Ilmenite	2	MgO	.9
Calcite	1	CaO	1.2
Total	100	Na_2O	1.6
		K_2O	1.8
		H_2O	1.3
		CO_2	.4

One must conclude that the chemical analyses of the graywackes and subgraywackes as listed by Pettijohn and others are not fully representative of the range of material which they consider to fall into the assigned compartments of their classifications.

METAMORPHOSED SILTSTONES AND SHALES

The finer grained metasedimentary rock (grain size predominantly less than 0.05 mm) of the Pinal schist include thin dense unfoliated siltstone, slate with excellent cleavage, phyllite which is commonly knotted, and fine-grained mica schist.

The least metamorphosed siltstones are typically dark gray and are closer to the sandstone in texture than to the very fine grained slate. Graded bedding is occasionally seen within them, particularly if a few sand grains are present. Compositionally they are essentially identical with the matrix material of the coarser beds. They occur as thin individual interbeds in the sandstone and also as intermediate phases of beds that grade vertically from sandstone to slate. They are metamorphosed to fine-grained very light gray quartz-mica schist locally and in this form are a constituent of the thick sericite schist units mapped in the northern part of the little Dragoon Mountains.

The slates and phyllites occur as thin interbeds in sandstone and as the upper part of individual graded beds. They also form thicker intervals, as much as 100 feet, in the graywacke-slate sequence and a considerable part of the sericite schist map unit in the Little Dragoons. In their least metamorphosed form, they are typically gray to dark blue gray and may show laminar banding of lighter gray or gray-green beds. At a few places banded slate units display highly contorted beds whose unsymmetric folds and breaks appear to be the result of some type of original sedimentary slumping. This phenomenon is confined to the slate unit and is not shared by the adjacent sandstone beds. At places in the graywacke-slate sequence, the top of a slate bed was evidently channeled on a scale of fractions of an inch before the overlying sandstone was deposited. The channels are usually marked by a concentration of coarse grains in the overlying sandstone bed. This phenomenon has been used to check and supplement graded bedding in determining the tops of beds.

Compositionally, the slates and phyllites are more sericitic than chloritic. An estimated average mineral composition for a representative slate or phyllite is:

	Percent
Sericite	45
Chlorite	15
Quartz	35
Feldspar	2–3
Magnetite and ilmenite	2–3
Epidote	Trace
Tourmaline	Trace
Zircon	Trace
Apatite	Trace

Flow cleavage is well developed, and, in places, one or more conspicuous lineations exist in the form of sets of persistent fine wrinkles. Faint to lustrous sheens appear on the cleavage as the phyllitization of the rocks increases. The microscopic texture is lepidoblastic, and the fine-grained quartz is largely obscured by the "fluidal" micas. The wrinkles common in hand specimens are reflected microscopically by folds and false cleavages that intersect the schistosity.

Many of the phyllites and fine-grained mica schists are spotted or "knotted" by numerous dark-green porphyroblasts 0.5 to 4 mm in diameter. These "knots" are elongated parallel to the local fold axes in some outcrops, but commonly they show a more or less random orientation. The knots are surrounded by a phyllitic to schistose matrix, coarser in texture but similar in composition to the less recrystallized slates and phyllites.

Two types of knots are visible microscopically, commonly in the same specimens. One type consists of chlorite, probably clinochlore, in ragged, poikiloblastic plates as much as 1 mm in diameter. The plates commonly lie athwart the foliation. In some specimens, relics of biotite are preserved in the chlorite, and therefore the chlorite is regarded as pseudomorphous after biotite.

The second type of knot is an aggregate rich in chlorite compared with the surrounding material; this chlorite is fine grained and includes much undigested sericite, quartz, and opaque material. The aggregates are generally lenticular and oriented in the plane of the principal foliation. The largest are as much as 4 mm long. The arrangement of inclusions preserves some original details of bedding and suggests that the chlorite has replaced skeletal porphyroblasts. This interpretation is supported by remnants of a skeletal mineral, with low positive relief and low first-order birefringence, preserved in the knots of a few thin sections; this mineral is probably cordierite, but it is too full of inclusions to permit positive identification. The cordierite(?) of some specimens evidently was rotated after it was formed, for the planar structure shown by inclusions within the knots lies at various angles (commonly 40° to 70°) to the foliation of the surrounding material. At the corners of the rotated knots, there are pressure shadows of sericite-free quartz in various stages of development. The sericite and chlorite of the enclosing rock are strongly oriented and "flow" around the knot.

METARHYOLITE FLOWS

Metamorphosed rhyolite flows are a minor constituent of the Pinal schist in the Dragoon quadrangle. The main occurrences are in the form of lenses, with a maximum size of 500 by 2,800 feet. These lenses are confined to a narrow zone trending northeast and passing about half a mile north of Lime Peak in the Little Dragoons. A small rhyolite outcrop a mile west of Johnson is tentatively regarded as a flow. The flows are similar in lithology to rhyolite porphyry intrusive bodies of early Precambrian age cutting the schist and described on page 23–25. The similarity suggests a genetic connection, but this has not been demonstrated as yet, and the intrusive bodies are certainly younger and could be considerably younger than the flows. Distinction of extrusive from intrusive rhyolite was based on field relations.

The best evidence of lava-flow origin was found in the largest rhyolite lens centering about 1¼ miles southwest of the Seven Dash Ranch. This lens is concordant with the Pinal metasediments, and the beds on both sides have their tops to the northwest as shown by graded bedding. The rhyolite in the central and greater part of the lens is massive and homogeneous. Finer grained but still massive and homogeneous rhyolite, evidently representing a chilled zone, is found along the southeastern side. The northwestern side is also chilled, but, unlike the southeastern, it grades into a breccia composed of very fine grained conspicuously flow-banded rhyolite fragments as much as 10 inches in diameter. It seems clear that the lens represents a lava flow with a once-glassy flow-breccia top poured out while the Pinal sediments were accumulating.

The rhyolite lens just described is one of a group of rhyolite lenses arranged in a zone that can be traced for nearly 3 miles parallel to the bedding and schistosity of the adjacent metasediments. Relict pyroclastic textures, preserved along the northwest side of several but not all the masses, suggest a flow origin for all, and they are so shown on the geologic map. The lenses can be interpreted as separate flows at about the same stratigraphic horizon or as parts of a single flow pulled apart during the Precambrian orogeny. Supporting the disruption interpretation are the lithologic similarity and alinement of the lenses and the generally more sheared and schistose character of the rhyolite in their tips.

The best preserved rhyolite is a gray porphyry with scattered phenocrysts of quartz and plagioclase 1 to 4 mm in diameter in an aphanitic groundmass. Magnetite, as sparsely distributed tiny crystals, can commonly be distinguished with a hand lens. The quartz and plagioclase phenocrysts are generally present in about equal quantities and together make up about 10 percent of the rock.

As seen in thin section the quartz phenocrysts have the rounded and embayed outline characteristic of siliceous porphyries. The plagioclase phenocrysts are subhedral to euhedral albite (about An_5), which contain abundant inclusions of sericite. The groundmass is a fine-grained intergrowth of alkalic feldspars, quartz, and sericite; it contains opaque grains and small quantities of biotite and chlorite. The groundmass grains are generally less than 0.05 mm in diameter. The sericite tends to have parallel orientation even in the least sheared specimens. Biotite and chlorite occur as fine flakes dispersed in the groundmass and also as scarce aggregates 0.1 to 0.2 mm in diameter that probably have replaced a primary ferromagnesian mineral. Accessory apatite and occasionally sphene and zircon are associated with these aggregates and with the larger opaque grains.

A rapid chemical analysis of a relatively well preserved specimen of extrusive rhyolite is given as analysis 1 in the following table. The analysis indicates a highly siliceous rock, with a chemical composition resembling the obsidian from Yellowstone Park (analysis 2). The rhyolite is in the group of sodic rhyolites, which approach rhyodacite (=quartz latite) in composition. It is distinctly higher in SiO_2 and lower in MgO and CaO than the other analyzed rhyolites of Precambrian age from Arizona (analyses 3, 4, 5), which are even more closely allied to rhyodacite (analysis 6). The closest counterpart in Arizona is the rhyolite schist of the Ray district (analysis 3) which Ransome (1919, p. 34) regarded as probably a lava flow because its field relations indicated it "was once a fairly regular layer in those sediments and not an irregular intrusion." The validity of this criterion of flow origin is questionable in view of the occurrence in the Dragon quadrangle of numerous mostly concordant intrusive sheets, described following the description of the Pinal schist. Analyses 4 and 5 represent this intrusive rhyolite.

Analyses of rhyolite and rhyodacite

	1	2	3	4	5	6
Chemical analysis						
SiO_2	76.00	74.70	72.87	69.60	70.45	69.33
Al_2O_3	12.30	13.72	12.89	14.50	14.08	14.23
Fe_2O_3	2.50	1.01	2.40	3.70	2.09	2.00
FeO	1.00	.62	1.76	.74	1.62	1.90
MgO	.32	.14	.82	.73	1.00	1.00
CaO	.31	.78	1.90	1.20	2.06	3.31
Na_2O	3.40	3.90	3.01	2.90	3.54	3.72
K_2O	3.80	4.02	3.03	4.60	3.35	3.15
TiO_2	.25	.00	.66	.60	.59	.29
P_2O_5	.16	.00	.13	.27	.17	.10
MnO	.04	Tr.	.07	.04	.07	.13
H_2O+	.48	.62	.64	.84	1.05	.94 (H₂O+ and H₂O−)
H_2O-	.02	------	.26	.02	.07	
CO_2	.08	------	------	.35	------	------
FeS_2	------	.40	------	------	------	------
Total	100.66	99.91	100.44	100.09	100.14	100.10
Sp gr (lump)	2.63	2.345	------	2.65	------	------
Sp gr (powder)	2.68		------	2.70	------	------
Normative analysis						
Salic						
Quartz	40.6	34.86	38.76	32.4	30.48	27.14
Orthoclase	22.2	23.35	17.79	27.2	20.02	18.63
Albite	28.8	33.01	25.15	24.6	29.87	31.44
Anorthite	1.7	3.89	9.45	3.6	10.29	12.79
Corundum	2.0	1.53	1.22	3.4	.82	------
Total	95.3	96.64	92.37	91.2	91.48	90.00
Femic						
Diopside	------	------	------	------	------	2.97
Hypersthene	0.8	0.66	2.00	1.8	2.90	2.65
Ilmenite	.5	------	1.22	1.1	1.06	.55
Magnetite	2.6	1.39	3.48	.7	3.02	2.90
Hematite	.8	------	------	3.2	------	------
Total	4.7	2.05	6.70	6.8	6.98	9.07
CIPW classification	I.3.1.3.	I.3.1.3.	I.3.2.3.	I.3.2.3	I.4.2.3.	I.4.2.4

1. Metarhyolite lava flow, Little Dragoon Mountains, SE¼ sec. 20, T. 15 S., R. 22 E. Rapid analysis, P. L. D. Elmore, K. E. White, and P. W. Scott, analysts.
2. Black obsidian, Obsidian Cliff, Yellowstone National Park. J. E. Whitfield, analyst (Iddings, 1888, p. 282).
3. Rhyolite schist, Granite Mountain, Ray district, Arizona. George Steiger, analyst (Ransome, 1919, p. 36).
4. Rhyolite porphyry stock, Little Dragoon Mountains, SE¼ sec. 18, T. 15 S., R. 22 E. Rapid analysis, P. L. D. Elmore, K. E. White, and P. W. Scott, analysts.
5. Rhyolite porphyry intrusive sheet, Johnny Lyon Hills, SE¼ sec. 16, T. 15 S., R. 21 E., W. J. Blake, analyst.
6. Average of three rhyodacites (227E) from Johannsen (1932, v. 2, p. 358).

The present chemical composition of the analyzed lava flow from the Little Dragoons doubtless reflects some metasomatism during its long history. Though the rock is relatively little sheared and its plagioclase phenocrysts retain their lustrous cleavage surfaces, it is cut every few inches by intersecting shear fractures spangled with sericite, which suggests that solutions may have passed through the rock.

With increasing metamorphism the groundmass of the rhyolite becomes increasingly foliated, and the phenocrysts lose their characteristic shapes by granulation and recrystallization. The resulting rock is very difficult to distinguish from the metamorphosed clastic sediments, and as a result some rhyolite flows may have been missed in the more intensely metamorphosed areas.

Rhyolite flows in the Pinal schist could be expected, in view of the common occurrence of recognizable rhyolite fragments in the clastic sediments that make up most of the formation. Units that may represent rhyolitic crystal and vitric tuffs have been described in connection with the metamorphosed sandstone. Other described occurrences of volcanic rhyolite in the lower Precambrian rocks of Arizona have been summarized by Anderson (1951). The occurrences closest to the Dragoon quadrangle are the Red Rock rhyolite of the Mazatzal Mountains (Wilson, 1939, p. 1120–21, 1129) and possibly the rhyolite schist at Ray.

METABASALT

Many concordant masses of metabasalt, now represented by dark-green amphibolite and chlotite schist, occur in the sericite schist-metagraywacke map unit of the Little Dragoons. The largest body, which is near the Seven Dash Ranch and partly concealed beneath the Apache group, is an irregular composite lens with a maximum exposed width of 3,000 feet and length of 7,000 feet. A zone of tabular bodies, individually as much as 3,000 feet long and 300 feet wide, is east of

Lime Peak. Other smaller bodies are southeast of Lime Peak and in a swarm extending from the Homestake prospect in Sheep Basin for 3½ miles southwestward to the alluvial cover near San Pedro Ranch. Some of the small bodies have hooklike outlines, perhaps owing to isoclinal folding and shearing off of one limb. The only other occurrences of the metabasalt in the quadrangle are as inclusions in the Precambrian intrusive rhyolite northwest of the Seven Dash Ranch and in the Johnny Lyon granodiorite. These inclusions evidently were derived from parts of the chist that have been eroded away, engulfed by the intrusions, or concealed by younger sedimentary rocks.

The typical metabasalt is a dark-grayish green fine-grained rock, and its individual crystals are generally less than 0.5 mm in diameter. Foliation is inconspicuous in the center of the larger bodies but generally plainly visible near the margins, particularly in the narrow tapering ends of the masses. Most of the small bodies are well and uniformly foliated. The few primary textures and structures preserved suggest a volcanic origin. The most common of these are amygdules of white quartz which have been noted in parts of the large body near the Seven Dash Ranch and in several of the other bodies. In the least sheared and recrystallized specimens, the amygdules are round or oval in cross section, generally 3 to 10 mm in diameter, and the outer boundary is smooth and sharp. Some are entirely quartz, whereas others have a narrow outer rim of chlorite or amphibole. At places in the small bodies southeast of Lime Peak, there are possible pyroclastic and pillow structures, but they are not sufficiently well preserved to be interpreted unequivocally.

Other evidence supplements the meager internal evidence of volcanic origin. The metabasalt is commonly associated in space with beds of purplish-red chert, resembling the ferruginous cherts found with many subaqueous basic flows. The chert beds are lenticular and individually less than 500 feet long and 15 feet thick. They occur immediately adjacent to the metabasalt masses or interbedded with the clastic sedimentary rocks within a few hundred feet of the basalt. No beds of similar lithology have been observed in other parts of the schist. Also suggesting a volcanic origin is a conglomerate, composed largely of mafic volcanic debris, found next to a metabasalt mass southeast of Lime Peak. The scattered external and internal evidence, taken together, suggests that much, perhaps all, of the metabasalt represents mafic lava flows. Some could represent mafic intrusions.

The metabasalt has been reconstituted mineralogically. One of the least modified masses is the largest tabular body east of Lime Peak. This mass is little sheared, and the finer grained border phase near the north margin contains well-preserved amygdules of quartz with rims of chlorite. All parts of the rock have been thoroughly reconstituted to low-grade metamorphic minerals; there are albite (An_{5-10}), quartz, chlorite, epidote, muscovite, and calcite. The coarser grained central part displays some relict ophitic or intergranular texture that is due to the preservation of tabular plagioclase crystals, 1 mm or less in length. The plagioclase and quartz in the chilled(?) border phase are too fine grained to be distinguished except under favorable conditions.

Rapid chemical analyses and estimated modes of the two phases are given in the following table, with Daly's (1933) averages of plateau basalt and andesite for comparison.

Analyses of metabasalt compared with plateau basalt and andesite

	Amygdaloidal border phase (W. J. Blake, analyst)	Massive central phase (W. J. Blake, analyst)	Average plateau basalt (Daly, 1933, p. 17)	Average andesite (Daly, 1933, p. 17)
Rapid chemical analysis				
SiO_2	56.50	65.50	48.80	59.59
Al_2O_3	12.78	13.67	13.98	17.31
Fe_2O_3	9.70	3.09	3.59	3.33
FeO	8.91	2.12	9.78	3.13
MgO	4.94	4.78	6.70	2.75
CaO	.43	.43	9.38	5.80
Na_2O	1.60	2.82	2.59	3.58
K_2O	1.39	1.28	.69	2.04
H_2O (total)	3.56	2.45	1.80	1.26
TiO_2	2.57	2.49	2.19	.77
P_2O_5	.30	.27	.33	.26
MnO	.15	.09	.17	.18
Total	102.83	98.99	100.00	100.00
Estimated mode				
Epidote	5–7	5–7		
Chlorite	40	15–20		
Muscovite	10	10–15		
Plagioclase	35 (plagioclase and quartz)	45		
Quartz		10–15		
Sphene and leucoxene	2–3	2–3		
Calcite	2	0		
Iron oxides	4	2–3		

The analyses suggest the lava flow represents a basalt or andesite that is now considerably modified in composition. The border phase, which is probably closest to the original rock in composition, suggests a silicified basalt from which most of the calcium has been removed. Part of the high iron content, compared with that of the central part of the flow and of average basalt, could be due to primary concentration of this element near the upper(?) surface of the flow. Silicification was more intense in the central part of the flow and appears to have been accompanied by removal of iron and some introduction of sodium. Whether the changes in composition took place at the time of volcanic activity, during the Precambrian regional metamorphism, or at some other time has not been determined.

Other specimens of the metabasalt examined under the microscope are either green schists generally similar in mineralogy to the analyzed specimens, or they are amphibolites indicative of a higher grade of metamorphism. From estimates made in thin section, the range in mineral composition of the various facies is as follows:

	Greenschist facies (percent)	Amphibolite facies		
		Near Seven Dash Ranch (percent)	Inclusions in Johnny Lyon granodiorite	
			Least modified (percent)	Most modified (percent)
Amphibole	----	45–70	55	25
Epidote	5–15	5–25	1–2	----
Chlorite	20–50	5–10	----	----
Biotite (and chlorite pseudomorphs).	----	----	3–5	12–15
Plagioclase }	25–60	5–15	{ 40	40
Quartz }			{ 1–2	15
Muscovite	5–15	----	----	----
Microcline	----	----	Tr.	3–5
Calcite	0–15	1–4	----	----
Sphene and leucoxene	1–3	5–10	½	½
Iron oxides	3–5	0–2	Tr.	Tr.

Both the green schist and the amphibolite facies are represented in the large body near the Seven Dash Ranch. The central and greater part is weakly foliated amphibolite, in which hornblende is the predominant constituent. The hornblende is pleochroic in pale yellow (X), green (Y) and blue-green (Z) and has an extinction angle $Z \wedge c = 17°–19°$. Epidote differs in amount from specimen to specimen. Quartz and sodic plagioclase are relatively scarce and cannot always be distinguished from one another. The texture is granoblastic and fine grained; the individual crystals rarely exceed 0.3 mm in diameter. In some specimens there are dark-green spots, about 1 mm in diameter, made up of subparallel commonly bent hornblende fibers, which evidently have replaced some primary mafic mineral. These hornblende aggregates and scarce amygdules of quartz are all that remain of the original texture.

The amphibolite of the Seven Dash Ranch body grades, in the tapering prongs of the mass and at some other places near the borders, into well-foliated chlorite schist. This rock lacks amphibole and is about 50 percent chlorite. It contains distinctly less sphene and more albite, quartz, calcite, and iron oxides than the amphibolite. Muscovite, in moderately thick plates 1 to 4 mm in diameter, generally makes up 5 to 10 percent of the rock. The chlorite schist is regarded as a lower grade metamorphic facies of the same rock which at a higher grade gave rise to the amphibolite. Incipient chloritization in the amphibolite and localization of the chlorite schist as a sheared border phase suggest the chlorite schist formed by retrogressive metamorphism of the amphibolite.

Amphibolite inclusions in the Johnny Lyon granodiorite show various stages of modification and reaction with the granodiorite magma. The inclusions occur principally in an irregular area of about 50 acres in the southern half of sec. 5, T. 15 S., R. 21 E. They range from a few inches to tens of feet in diameter and are clotted together in contaminated granodiorite. Scattered small masses of modified amphibolite and hybrid granodiorite are common throughout a large area to the west and southwest of the area in which inclusions are abundant.

The least modified inclusions are a foliated gray-green rock, which weathers brown. The rock consists essentially of fine-grained plagioclase and black hornblende. (See preceding table.) Most of the grains are less than a millimeter in diameter, but scarce scattered plagioclase crystals are as much as 5 mm long. Some of the hornblende is in fine-grained lenticular aggregates as much as 10 mm in diameter. These lenses of hornblende are flat and have a strong parallel orientation. Ellipsoidal amygdules of quartz rimmed by hornblende are common. The amygdules are as much as 8 mm long and are alined with the foliation.

This least altered phase grades into a mafic medium- to coarse-grained igneous-appearing hybrid rock. The foliation is almost but not completely lost. The hornblende aggregates are recrystallized into fewer and larger crystals and are no longer conspicuous. The hornblende-rimmed quartz amygdules, although recrystallized, are recognizable in even the most modified phases. Quartz, biotite, and microcline appear in increasing amounts, and the amount of hornblende decreases. (See preceding table.)

The modifications involve recrystallization, reconstitution, and silicon and potassium metasomatism. The order of appearance of minerals in the inclusions is the same as the sequence of crystallization in the granodiorite: first, hornblende and plagioclase, then biotite, quartz, and potassium feldspar in that order. The changes in mineralogy reflect, to a somewhat stronger degree, the shifting equilibrium of the phases within the granodiorite. During the deuteric stages of crystallization in the latter, identical modifications took place in the inclusions and the host rock. In general, the modifications tended to eliminate concentration gradients and to make inclusion and host similar to one another.

These amphibolites, clearly of contact metamorphic origin, contain less epidote and distinctly more abundant and more calcic plagioclase than the amphibolite near the Seven Dash Ranch. The plagioclase in the inclusions is characteristically calcic oligoclase in the range An_{25-30}. The optical properties of the hornblende pleochroism—X, pale yellow, Y, green, Z, dark blue-green; absorption $X<Y<Z$; indices $\alpha=1.646$, $\beta=1.661$, $\gamma=1.669$; $2V$ (calculated)$=71°(-)$, $Z\wedge c=18½°$—establish its essential identity with the hornblende in the granodiorite. The hornblende in the least modified inclusions contains rare actinolitic cores, which indicate derivation from a lower grade metamorphic rock, perhaps similar to the analyzed green-schist specimens from the Little Dragoon Mountains.

THICKNESS

The Pinal schist near the Johnny Lyon Hills probably represents at least 8,000 feet of beds. The schist is exposed for a width of 9,000 feet, normal to its strike, along a northwest line between the pre-Apache unconformity in the NW¼ sec. 14, T. 15 S., R. 21 E., and intrusive granodiorite near the southeast corner of sec. 4, T. 15 S., R. 21 E. Along this line, the average dip of the beds is approximately 80°, and scores of close-spaced graded-bedding observations indicate the top of the beds is to the northwest. There is one clearcut reversal in the top direction, but this reversal can be limited to less than 200 feet of beds; it probably represents a minor isoclinal fold. Near the base of the Apache group, close-spaced reversals in graded bedding indicate tight isoclinal folds. Eliminating the latter part of the section and allowing for the other reversal, about 8,000 feet of beds remains and is interpreted as forming a continuous section with its top to the northwest.

The thickness of the Pinal schist exposed in the Little Dragoons cannot be estimated accurately because of minor folding and lack of knowledge of the details of structure in many parts of the schist. Graded bedding was found in abundance only northwest of a line defined by Lime and Johnson Peaks. Most of the graded bedding in this area indicates the top of the beds is to the northwest, but there are many reversals involving from a few feet to perhaps 600 feet of beds. A few determinations of bed tops south of the Lime Peak-Johnson Peak line suggest similar structure.

Graded bedding and the lack of repetition of large lithologic units suggest that, in the Little Dragoons north of the Texas Canyon quartz monzonite stock, the entire Pinal section has its top to the northwest, except for local reversals due to isoclinal folds. In some areas the cumulative effect of folds in duplicating beds is great, and the apparent stratigraphic thickness is much larger than the true thickness. For example, the sericite schist unit northwest of the Seven Dash Ranch has an apparent thickness of 1,300 feet; but this thickness is certainly too great because, a short distance to the south, two rather large anticlines cause deep reentrants of interbedded metagraywacke and sericite schist and unquestionably also duplicate the sericite schist unit in this locality (pl. 1). The actual thickness of this sericite schist unit is only 400 feet, if its unfolded prong on the west is representative. This extreme thickness exaggeration, 325 percent, is due to the large number and size of minor folds in this area. The complex folding was presumably localized by the incompetent shaly unit. In other parts of the schist, where numerous close-spaced graded beds were found, the thickness exaggeration is on the order of 5 to 20 percent.

Assuming the suggested interpretation of structure is correct and the average duplication by folding is 50 percent, the thickness of Pinal exposed in the Little Dragoons is about 12,000 feet. The section is much more diversified lithologically than the one near the Johnny Lyon Hills, and hence the two probably are not duplicate sections. By adding the two sections together, an admittedly very rough estimate of 20,000 feet is obtained for the total thickness exposed in the two areas.

CONDITIONS OF DEPOSITION

The Pinal schist in the Dragoon quadrangle consists of metamorphosed sedimentary and volcanic rocks, probably on the order of 4 miles thick. No important unconformities in the section have been recognized, and neither top nor bottom is exposed. The lithologic characteristics indicate deposition in a major geosyncline.

Among the many types of geosynclines reported or suspected by students of sedimentation and tectonics, the best documented are major linear troughs on the margins of continental interior shields or cratons. Typically, these geosynclines are separated into a miogeosyncline near the stable shield and an outer deeper eugeosyncline where volcanic piles form geanticlinal arcs. These arcs are major sources of debris, and their volcanic clastic material and flows are characteristic of the eugeosynclinal deposits. Volcanic material becomes subordinate to continental debris in the miogeosynclinal lithology.

The Pinal schist of the Dragoon quadrangle was probably deposited in a eugeosyncline. The major aspects of the formation, including its great thickness, the cyclic graywacke-slate lithology, the graded bedding, the intercalated lava flows, and the abundant volcanic debris in the sediments, are characteristic of eugeosynclinal deposits (Pettijohn, 1949, p. 443–449). Clean sandstones, carbonate rocks, crossbedding, ripple marks, or other features of shallow marine environments are lacking. The schist seems to represent a deep-water accumulation, nourished perhaps by turbidity currents. Kuenen (1950, p. 238–240) ascribed graded bedding and many coarse abyssal deposits to this transportation mechanism.

The source of the clastic sediments is not known, but it must have been diverse geologically. Volcanic terranes yielded much of the debris, but metamorphic rocks, particularly quartzite, slate, and phyllite, were equally well represented, and granophyric and granitic rocks yielded some recognizable fragments. Zircons separated from several graywacke beds for purposes of age determination display a wide variety of crystal habits, colors, and degrees of abrasion and therefore must have had a heterogeneous source.

Possible source rocks older than the Pinal schist have never been recognized in southern Arizona. The oldest rocks in central Arizona, the Yavapai schist, and in the Grand Canyon area, the Vishnu schist, have the same geologic relations and general lithologic characteristics as the Pinal. Though the relative abundance of volcanic material is different at different places in each of these formations, there is no present basis for separating them. The simplest interpretation is that they were formed in the same major geosyncline, though perhaps not strictly contemporaneously. In his comprehensive review of the older Precambrian of Arizona, Anderson (1951, p. 1345) emphasized the repetitious character and lenticularity of the volcanic and sedimentary units and wisely cautioned against distant correlation. The lenticularity and local variation in abundance of volcanic rocks would be expected in a geosyncline having geanticlinal arcs of active volcanism. Debris from metamorphic and intrusive igneous rocks could have been derived from the geanticlines or from lands that bordered the geosyncline.

METAMORPHISM

The Pinal schist shows the effects of several types and periods of metamorphism. All parts of the schist were affected by regional metamorphism during a major Precambrian orogeny, which Wilson (1939, p. 1161) has called the Mazatzal revolution. During this revolution, which preceded deposition of the Apache group of late Precambrian age, susceptible units like the basalts were reconstituted mineralogically, and all the units were modified dynamically, with the formation of cleavage, schistosity, and boudinage. During later periods of metamorphism, these older metamorphic features were modified and even obliterated locally. Contact metamorphism was associated with igneous intrusions, particularly the large bodies of granitic rock. The contact metamorphosed schist adjacent to these bodies locally extends as much as a quarter of a mile from the intrusive contact and consists characteristically of a narrow inner zone of hornfels, in which the older metamorphic textures and structures have been erased, and a much broader outer zone of recrystallized schist. Cataclastic effects were superimposed during the Laramide orogeny of Late Cretaceous or early Tertiary age. These effects are not evident in all parts of the schist but in places are so intense as to obliterate the older features. Only the more general and pervasive metamorphic features of the schist will be discussed in this section, those of local or special interest being deferred to other parts of the report.

REGIONAL METAMORPHISM

The dynamic effects of regional metamorphism are generally more conspicuous in the Pinal schist than are the thermal effects. Schistosity, very nearly parallel to the beds in most outcrops, is the most widespread feature. The schistosity takes the form of a pervasive cleavage in the slate and phyllite but is only weakly expressed in the associated metagraywacke. It is an axial-plane slaty cleavage in relation to tight isoclinal folds and asymmetrical drag folds in the beds. Recrystallization has emphasized the foliation where metamorphism was more intense than in the slate areas. Where deformation produced boudinage, the major and intermediate axes of the boudins lie in the plane of the schistosity. Flattened pebbles and tabular or elongate porphyroblists also lie in this plane.

Associated with the schistosity are several types of lineation. These lineations include intersections of bedding and schistosity, wrinkling in the schistosity, pencil structures in the slate, boudinage structures, elongate porphyroblasts and mineral streaks, and stretched pebbles. Several of these elements commonly occur together and are parallel. At places it may be seen that they are also parallel to minor fold axes, which were themselves the bases for some of the lineation measurements mapped. All the lineations may be classified as *b*-lineations after the reference axes of Sander (Cloos, 1946, p. 5–6).

South of Lime Peak and also south of the Johnny Lyon Hills, the Pinal schist displays another conspicuous lineation, in addition to those just mentioned. This second lineation, which has been mapped, has the form of horizontal to gently dipping parallel wrinkles or tiny faults in the plane of the schistosity. The wrinkles and faults are due to the intersection of a nearly horizontal fracture cleavage with the schistosity. The cleavage is found throughout local areas, particularly near Laramide thrust faults, but in most outcrops it is irregularly spaced and is in part only incipient. Under the microscope it has the appearance of a false cleavage distinctly younger than the schistosity. The attitude and distribution of the cleavage are taken as indications of origin during the Cretaceous or early Tertiary orogeny.

Thermal effects of the regional metamorphism are inconspicuous in much of the schist. In the least metamorphosed areas, the coarse-grained metasediments retain most of their origin texture and mineralogy. Recrystallization and reconstitution were confined to shale beds, the argillaceous matrix of the sandstone, the basaltic units, and the groundmass of the rhyolite lava. The recrystallization everywhere produced microschistosity, which brands these rocks as metamorphic. The metamorphic mineral assemblage in the metasediments (quartz, albite, muscovite, chlorite, epidote) is typical of their low metamorphic rank, and the rocks are texturally proper slate and graywacke. There is no evidence in many of these rocks to indicate they ever rose above the muscovite-chlorite subfacies of the greenschist facies as classified by Turner (1948, p. 96–97). If the biotite-chlorite subfacies was once attained in these rocks, retrogression has erased all evidence by which it is recognized elsewhere in the area.

In the more intensely folded and sheared areas, such as the southern end of the schist belt in the Johnny Lyon Hills and several areas in the Little Dragoons, the graywacke has been converted to micaceous quartz-feldspathic semischist, and the slate, to porphyroblastic phyllite and mica schist. The minerals include biotite, chlorite, muscovite, quartz, albite, and epidote. The biotite is commonly fine grained and associated with muscovite and chlorite; in some places it formed tabular porphyroblasts, which were largely replaced by chlorite during a retrogressive episode. The mineral assemblage in these rocks represent the biotite-chlorite subfacies of the greenschist facies (Turner, 1948, p. 94–95). No higher metamorphic grade has been recognized among the regionally metamorphosed Pinal sediments.

The basaltic members of the Pinal schist have been thoroughly reconstituted mineralogically. The flow east of Line Peak has a quartz-albite-chlorite-muscovite, epidote assemblage corresponding to the lowest grade indicated by the metasediments. At places, however, the metabasalt displays a hornblende-epidote-sodic plagioclase-quartz-chlorite assemblage indicative of the higher grade albite-epidote amphibolite facies (Turner, 1948, p. 88). This is the highest grade that can reasonably be attributed to the regional metamorphism, and it was reached only locally, as in the large metabasalt mass near the Seven Dash Ranch. Higher metamorphic grades, as in inclusions in the Johnny Lyon granodiorite, are the result of contact metamorphism.

CONTACT METAMORPHISM

Metamorphism due to heat and emanations from igneous intrusions has affected the Pinal schist several times. The earliest episode preceded the regional metamorphism and was due to rhyolite porphyry intrusions emplaced before or during the Mazatzal revolution. These effects were on a very minor scale and will be discussed in connection with the porphyry. Much more extensive contact metamorphism was associated with the emplacement of the Johnny Lyon granodiorite, Tungsten King granite, and Texas Canyon quartz monzonite. The large masses of these rocks have affected the intruded schist to widths ranging from a few feet to about a quarter of a mile.

The outer and greater part of the contact aureoles is characterized by simple recrystallization, best indicated in outcrop by the gradual masking of the schistosity and lineations and by the gradual coarsening of the grain size in the argillaceous beds The outcrops of metasediments are in places browner than usual because of iron oxide, probably formed by recent weathering of certain contact metamorphic minerals. This recrystallized zone grades into normal schist at the outer margin and into a zone of intense recrystallization and reconstitution near the intrusive body.

Pronounced recrystallization and reconstitution have taken place in schist inclusions in the granitic rock and in a band, at most a few hundred feet wide, immediately adjacent to the intrusive body. The schistosity has been erased from the metasediments, and the conspicuous structure is a compositional and textural banding that reflects the original alternation of graywacke and slate. The former graywacke beds are only slightly coarsened in texture but wherever studied in thin section have been completely recrystallized to granoblastic quartz-muscovite-biotite-plagioclase-microcline hornfels. The former slate has been completely transformed into coarse-grained porphyroblastic hornfels with mica plates as much as 1 cm in diameter and with andalusite prisms as much as 3 cm long and 1 cm in diameter. Both types of hornfels have been partly chloritized, and the latter type, at least in the vicinity of the Johnny Lyon granodiorite, contains chlorite pseudomorphs after a nearly equidimensional mineral, probably cordierite(?) or possible almandite(?). Sillimanite, found in contact-metamorphosed shale of the Bisbee group near the Texas Canyon quartz monzonite, was not detected in the Pinal schist.

The texture and mineralogy of the most metamorphosed sediments indicate the amphibolite grade modified by some later retrogression, probably of hydrothermal origin. Inclusions of metabasalt in the Johnny Lyon granodiorite also reached the amphibolite grade. The occurrence of anorthite-bearing plagioclase (calcic oligoclase) in this amphibolite implies a somewhat higher grade of metamorphism than that of the albite-epidote amphibolite that appears to have formed locally during the regional metamorphism.

Very little metasomatism accompanied the contact metamorphism of the schist. Silicon and potassium evidently were added to inclusions of metabasalt in the Johnny Lyon granodiorite. Some potassium also seems to have been added to the innermost zone of hornfels next to this intrusive; this addition formed late microcline and altered the andalusite to sericite. Generally similar effects near the Tungsten King granite and the Texas Canyon quartz monzonite are considered probable from field observations; schist inclusions in both have been made over into quartzose igneous-appearing rocks that in places contain porphyroblasts of potassium feldspar as much as 1 cm in length; andalusite near the Texas Canyon quartz monzonite has been altered to sericite.

Some conspicuous concentrations of tourmaline occur in the contact-metamorphosed schist near the Johnny Lyon granodiorite. The concentrations are of two types. At the north end of the schist belt, for a distance of about a mile, the schist near the intrusive body contains scattered short thin quartz veins in which radiating clusters and randomly oriented crystals of coarse black tourmaline as much as 2 inches long are common. Farther south in the NE¼ sec. 15 and the SE¼ sec. 19, T. 15 S., R. 21 E., black tourmaline-rich veins of a different type were noted. Each of these veins is 3 to 6 inches wide and can be traced for about 250 feet before disappearing. The veins are parallel to relict bedding in the schist and consist of a breccia of angular platy fragments of schist an inch or less in diameter in a dense black matrix. The matrix, which makes up 40 to 60 percent of the veins, is predominantly black tourmaline. Innumerable stubby prisms, averaging 0.1 to 0.2 mm in length, form a felty intergrowth with fine-grained quartz, iron oxides, and sericite. Brecciation does not extend beyond the tourmaline occurrence; it would appear that brecciation may have been a direct result of pneumatolytic or hydrothermal fluid surges along the bedding.

All but one of the tourmaline occurrences are so close to the contact of the intrusive body that boron migration associated with the plutonic emplacement is suggested. Though tourmaline has not been noted as an accessory mineral in the granodiorite, it does occur in some of the associated pegmatites. In general, tourmaline is very scarce in the Dragoon quadrangle. The only concentrations known are those associated with the Johnny Lyon granodiorite, and some small ones near the diabase of Precambrian age described in the section dealing with that formation.

The contact-metamorphosed schist near the Texas Canyon quartz monzonite southwest of Johnson is cut by quartz veins containing huebnerite, base-metal sulfides, and manganese oxides. At the Homestake prospect in Sheep Basin, a metabasalt unit contains small lenses of coarse-grained quartz, epidote, garnet, and gray-green amphibole, with disseminated scheelite and oxidized copper minerals. These occurrences are part of a large group of tungsten and base-metal deposits that are in and near the Texas Canyon quartz monzonite and are believed to be somewhat younger than contact metamorphism of the schist.

INTRUSIVE RHYOLITE PORPHYRY

DISTRIBUTION AND GEOLOGIC RELATIONS

Rhyolite porphyry intrusions clearly of earlier Precambrian age cut the Pinal schist near the north end of the Little Dragoons and in the Johnny Lyon Hills area (pl. 1). The easternmost and largest rhyolite mass, which crops out over an area of about 1¼ square miles, has an irregular intrusive contact with the Pinal schist on the south and east and is truncated on the north and west by unconformable sedimentary rocks of later Precambrian and Tertiary and Quaternary ages. Schistosity and relict bedding in the schist curve around the mass, so that some parts of the contact are nearly concordant. Distinctly discordant segments of the contact and crosscutting apophyses establish that the porphyry is an intrusive not an extrusive body. Some large inclusions of schist are found in the mass, and some small porphyry sheets and plugs are found in the schist near its contact.

A short distance southwest of the large rhyolite porphyry body, there is a similar but smaller body. Slightly farther west, part of another body appears east of the South Camp fault. About 4⅛ miles farther southwest, south of the Johnny Lyon Hills, part of a similar body crops out between the Pinal schist and the alluvial cover. This mass sends dozens of thin apophyses into the schist and is bordered by a number of thin satellitic porphyry sheets in the schist; the apophyses and sheets are too small to be shown on the geologic map.

The four bodies just described, which constitute all the larger bodies of rhyolite porphyry in the Dragoon quadrangle, occur within a northeast-trending zone parallel to the structural trend of the Pinal schist. Older Precambrian rocks are not exposed in other parts of this zone, and therefore it cannot be determined whether the alinement is fortuitous or whether it indicates an extensive zone of such intrusive bodies.

The shape of the bodies in outcrop suggests that they are stocks, and they are referred to as such in this report even though the outcrops provide almost no information on their shape below the surface. The other rhyolite porphyry intrusions in the area are tabular lenses and sheets very different from the stocks in outcrop pattern.

Nearly all the intrusive sheets are in a northeast-trending zone that passes about a mile north of the western porphyry stock. The zone is 800 to 1,000 feet wide and nearly parallel to the bedding in the Pinal schist. It is concealed for about a mile by the late Precambrian and Paleozoic rocks of the Johnny Lyon Hills and is offset by major thrust faults, but it is otherwise continuous for about 6 miles between the pre-Apache unconformity southwest of Deepwell Ranch and alluvium which conceals the zone about a quarter of a mile west of the map area.

Individual porphyry sheets in the zone are as much as 75 feet thick, and some are more than 2,000 feet long. The average size is probably 25 feet thick and 150 feet long.

The sheets occur repeatedly along two or three horizons within the zone for distances of a mile or more, but just as commonly have a random or an echelon arrangement in the zone. Most of the sheets and lenses are simple in form and grossly concordant with the adjacent beds. They dip so steeply that the outcrop pattern is a cross section almost normal to them. The ends of the bodies generally taper gradually and disappear. They may persist, with thicknesses less than 1 foot, for several hundred feet before disappearing or swelling into another body 20 or 30 feet thick. A single sheet may part and envelop a thin septum of metasedimentary rock. One side of the parted body may wedge out, whereas the other may part again. A single lens may terminate by sending several thin apophyses into the adjacent beds. In detail almost all the porphyry bodies truncate the beds somewhere along their contacts, particularly at the ends of the bodies. These are clearly intrusive contacts, for thin apophyses of porphyry commonly project concordantly along the bedding from a generally discordant contact.

A weak but consistently recognizable contact-metamorphic halo has been formed in the adjacent rocks on all sides, particularly in the slate and phyllite. In outcrop this is manifested only by a purple or lavender cast developed in the fine-grained rocks. In thin section the slate and phyllite from the contact zone differ from similar rocks elsewhere in containing 1 to 40 percent finely divided hematite, 1 to 3 percent epidote, an unusual abundance (as much as 40 percent) of nearly colorless chlorite, and abundant minute ptygmatic quartz veinlets. The finely divided hematite apparently causes the unusual color of the outcrop.

Both sheets and stocks are clearly of earlier Precambrian age as they intrude the Pinal schist and are truncated by the unconformity at the base of the Apache group. It is also clear they were emplaced before completion of the major Precambrian orogeny for they, like the Pinal schist, show effects of regional metamorphism not displayed by any of the younger rocks. They are therefore older than the mica rhyolite and the Johnny Lyon granodiorite, which are described later. It is possible the rhyolite porphyry magma was injected into the Pinal schist shortly after its deposition.

LITHOLOGY

The least altered rhyolite porphyry is a dark-brown rock, which weathers red brown to yellow brown; it is characterized by abundant large milky quartz phenocrysts, more numerous but less conspicuous feldspar phenocrysts, and a few dark aggregates, in a massive aphanitic groundmass. The phenocrysts are generally larger and more abundant than those in the rhyolite flows of the Pinal schist. This difference as well as the difference in color—characteristically brown to red rather than gray—assists in distinguishing the two rocks in their least sheared and altered phases.

No perceptible chilled zone or consistent textural variation between the center and margins of the rhyolite porphyry bodies has been observed, where the original margins are well preserved.

The quartz phenocrysts average about 4 mm but may attain 10 mm in diameter. They are rounded by resorption and show all stages of corrosion and embayment by the groundmass material (fig. 3). The feldspar

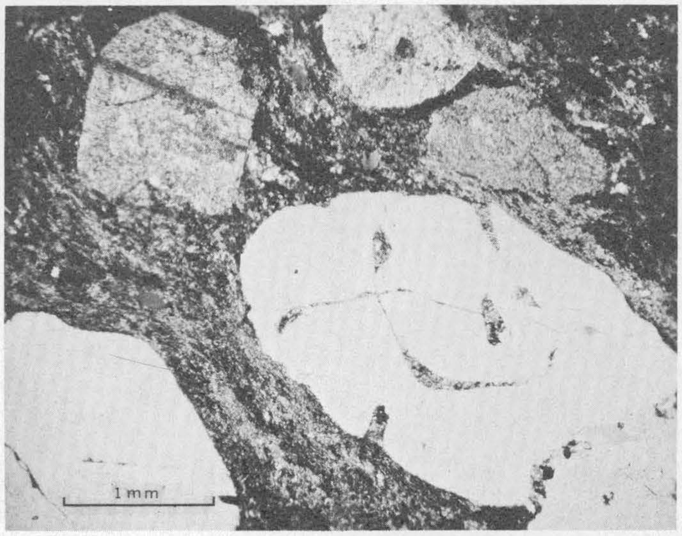

FIGURE 3.—Photomicrograph of rhyolite porphyry showing typical phenocrysts of resorbed quartz and altered sodic plagioclase in a fine-grained sericitic groundmass. Crossed nicols. × 20.

phenocrysts are sericitized and are sodic plagioclase in the range An_{5-15}. The feldspar is subhedral to euhedral, although sometimes broken, and ranges from ½ to 3 mm in diameter. The dark aggregates appear to be pseudomorphs after an original mafic mineral and are usually elongated intergrowths of magnetite, ilmenite, and some incipient biotite. Zircon and apatite are recognizable accessory minerals, usually associated with the dark minerals.

The groundmass is a very fine grained intergrowth of quartz, albite, and probably potassium feldspar. It contains 15 to 20 percent of sericite in all specimens examined. Minute crystals of biotite or chlorite are commonly associated with scattered opaque grains.

The rock is similar in its petrographic features to the rhyolite flows of the Pinal schist but on the average contains a higher proportion of phenocrysts as shown by the following estimates of the average composition of the two rocks:

	Intrusive rhyolite porphyry (percent)	*Rhyolite flow (percent)*
Phenocrysts:		
Quartz	10	5
Plagioclase	15	5
Pseudomorphs after mafic mineral	5	Trace
Groundmass	70	90

All the rhyolite porphyry shows the effects of alteration and dynamic metamorphism. The mafic phenocrysts have been thoroughly reconstituted, and the feldspar phenocrysts are invariably sericitized. Strongly oriented sericite is characteristic of the groundmass of every thin section examined. In the more metamorphosed parts, most commonly found on the margins and ends of the masses, the dense brown or red groundmass may be converted to pale-yellow or gray mica schist in which the feldspar phenocrysts have nearly disappeared because of granulation and sericitization and the quartz "eyes" have been sheared almost beyond recognition. Quartz veinlets and larger masses develop along the ends of the bodies apparently as segregations during reconstitution of the rock. The end product is a schist that is impossible to distinguish in hand specimen from some of the gritty quartz-sericite schists of sedimentary parentage. Such intense effects are common but are not the rule, and in general the porphyry has survived the regional metamorphism without losing its igneous identity.

Chemical analyses and norms of two specimens of the rhyolite porphyry are presented as analyses 4 and 5 on page 17. Analysis 5, representing the better preserved specimen obtained from an intrusive sheet in the Johnny Lyon Hills, supports the petrographic evidence that the porphyry is actually a rhyodacite, or quartz latite. Analysis 4, a rapid analysis of a sheared and considerably sericitized specimen from the large stock in the Little Dragoons, shows some striking similarities but has a considerably higher $K_2O:Na_2O$ ratio and a somewhat lower CaO content. These differences could be due to alteration, suggested by sericitization, and high Fe_2O_3 and CO_2 in the chemical analysis. The field term "rhyolite porphyry" has been preserved as a general name, because available analyses of the Precambrian rhyolitic rocks of Arizona, summarized in the table, suggest they may represent an unbroken series ranging from sodic rhyolite to quartz latite in composition.

MICA RHYOLITE

In the Pinal schist southwest of the Johnny Lyon Hills, generally concordant thin white mica rhyolite sheets, not shown on the geologic map, occur in a zone more than 2 miles long. This zone parallels the zone of rhyolite porphyry sheets, lies about 500 feet south of the latter, and shows similar offsets by thrust faults. It is characterized by a single line of slightly en echelon sheets for more than half its length, and for the remainder by a double line of sheets. Individual sheets range from 1 to 50 feet in thickness and from 50 feet to about half a mile in length. They tend to maintain a constant thickness and do not show the lenslike form of some of the rhyolite porphyry bodies.

The mica rhyolite is a white porphyritic-aphanitic rock that weathers creamy white or tan and is slightly more resistent than the adjacent metasediment and the nearby brown rhyolite porphyry bodies. The texture is uniform except for a 1- to 2-inch chill zone, where phenocrysts are not so abundant.

The phenocrysts are small, generally 0.5 to 2 mm, and are not very conspicuous, although they make up about 25 percent of the rock. They include quartz, sodic plagiolcase, muscovite, and rare grains of garnet. The quartz is subhedral to euhedral with dipyramidal β-quartz forms and shows only slight resorption effects. The feldspar is also subhedral to euhedral and is apparently plagioclase An_{5-15}, invariably much sericitized. The muscovite is in well-formed plates, which distinguish this rhyolite. Garnet, rounded to irregular and slightly pinkish in thin section, is present in some specimens.

The groundmass is a very fine grained (less than 0.05 mm) intergrowth of quartz, albite, potassium feldspar, and oriented sericite. An estimated average mineral composition of the rock is:

	Percent
Phenocrysts:	
Quartz	10
Plagioclase	12–15
Muscovite	2–3
Garnet	Trace
Groundmass	75

In contrast to the rhyolite porphyry in the nearby zone, the mica rhyolite generally shows no metamorphic modification on the margins or ends of the sheets. Sericite is the only alteration product visible; it is distinctly oriented in the groundmass but not as much as in the nearby porphyry. There are, however, a few small thin sheets of a schistose muscovite rhyolite found in the schist adjacent to the Johnny Lyon granodiorite. This rock, compositionally identical with the nonfoliated mica rhyolite, has it foliation parallel to the schistosity of the surrounding metasediments. A few small sheared and locally folded sheets of white rhyolite, that may represent the same magma, were noted in the Pinal metasediments between the Tungsten King mine and the Texas Canyon quartz monzonite in lower Sheep Basin.

The texture, composition, and field relations of the mica rhyolite demonstrate its intrusive igneous origin. It must be younger than the rhyolite porphyry because wherever the two rocks are found in proximity the mica rhyolite lacks the intense metamorphic effects displayed by the porphyry. The relations suggest the mica rhyolite was intruded after the major Precambrian orogeny was almost but not wholly completed. The relation of the Apache group to the mica rhyolite bodies is not altogether clear, but at one place south of Keith Ranch the pre-Apache unconformity seems to truncate a small unfoliated body of the rhyolite.

JOHNNY LYON GRANODIORITE

The name Johnny Lyon granodiorite is given to the large body of granitic rock exposed north and west of the Johnny Lyon Hills (Damon, 1959). Damon introduced the name into the literature, and it is here formally adopted by the U.S. Geological Survey. A small granodiorite outcrop southwest of Johnson has been referred doubtfully to the formation.

The outcrop pattern of the granodiorite (pl. 1) is crudely that of a segment of a circle modified in detail by post-Paleozoic faulting. The circular arc that defines the eastern boundary includes the intrusive contact with Pinal schist on the southeast and the unconformable contact with the Apache group on the northeast. The western boundary is nearly straight and coincides approximately with the edge of the map. It is defined by the edge of alluvium in the San Pedro valley and, at the north, by major thrust faults. The area of the segment is slightly more than 20 square miles. The granodiorite is also exposed near The Narrows of the San Pedro River several miles west of the Dragoon quadrangle.

The intrusive contact is sharp, with coarse-textured granodiorite immediately adjacent to the contact hornfels phase of the Pinal schist. Along the southeastern side of the mass, the contact is locally concordant, with foliation and relict bedding in the schist for distances as much as several hundred yards; but invariably the contact cuts obliquely across the beds if followed for greater distances. In general, the contact in all parts of its arcuate course trends 15° to 30° more northerly than structures in the schist. In detail, the contact pattern is complicated by numerous crosscutting and sill-like apophyses and by small aplite and pegmatite dikes that are not distinguished from the main phase of the granodiorite on the map.

The general dip of the intrusive contact is to the southeast. The trace of the contact on the topography and offsets along faults indicate a considerably flatter dip (30° to 50° SE.) than is characteristic of the schist (65° to 85° SE.). Numerous schist inclusions in the marginal areas of the granodiorite commonly have their internal structure parallel to that of the wallrock; this parallelism indicates that they are roof pendents and suggests that the general projection of the contact was not far above the present land surface.

In considering the original roof and walls of the pluton, one must bear in mind the postintrusion tilting indicated by the present altitude of the Apache group south of Kelsey Canyon. The Apache group dips 40° to 65° E. in this area. If the pre-Apache erosion surface is rotated to a horizontal position about an axis parallel to the present strike of the unconformity, then the northeastern end of the granodiorite-schist contact appears to be part of the original roof, which steepens southward and forms the wall of the pluton. Where the Apache group rests directly on the granodiorite as it does north of the Willcox-Cascabel road, the original roof was removed in Precambrian time.

The Johnny Lyon granodiorite is nonresistant to erosion and has been reduced to two well-developed bedrock surfaces, one formed by tributaries of the San Pedro River and the other by tributaries of Tres Alamos Wash. These surfaces, which are known locally as the River Slope and the Mesa, respectively, are characterized by low relief except along the drainage divide where the steplike discordance between the higher Mesa and lower River Slope involves a difference of 150 to 250 feet in elevation. The location of this break is controlled in part by a major altered and silicified zone which is more resistant than the rest of the granodiorite.

Northwest of Keith Ranch the granodiorite forms a group of hills with relief of more than 1,000 feet. The granodiorite in this area seems to be more resistant as a result of structural complications. It also seems probable that it was capped until relatively recent time by a thrust sheet of Paleozoic sedimentary rocks similar to the sheets in the central and eastern parts of the Johnny Lyon Hills.

LITHOLOGY

The Johnny Lyon granodiorite is uniform in mineral composition and texture, except for several subsidiary phases that include (a) a hybrid phase associated with some inclusions, (b) pegmatites and aplites, (c) hydrothermal alteration zones, and (d) a wide variety of cataclastic modifications. These minor phases make up only 2 or 3 percent of the total area of the exposed intrusive body.

MAIN PHASE

The main phase is typically a medium- to coarse-grained somewhat porphyritic gray to gray-green hornblende-biotite granodiorite. In hand specimen, coarse white plagioclase, gray quartz, scattered pink potassium feldspar, dark-green platy biotite and greenish-black prismatic hornblende are the principal minerals seen. Brilliant brown euhedral sphene crystals, ⅓ to 2 mm in diameter, are commonly visible as a minor constituent.

Upon weathering, the rock assumes a pink-brown cast, against which yellowish- to greenish-white plagioclase crystals stand out in contrast to the iron oxide-stained quartz and chloritized biotite and hornblende. The rock disintegrates readily into fragments 2 to 10 mm in diameter.

In thin section the fresh rock can be described as medium to coarse grained hypidiomorphic-granular, commonly with a slight seriate porphyritic texture. Plagioclase crystals, as much as 15 by 10 mm, are subhedral to euhedral, tabular, and zoned. They range in composition from An_{32-35} at the cores to An_{20-22} at the rims. Oscillatory and reverse zoning are common, but the rims are consistently more sodic than the cores. The usual alteration minerals in the plagioclase are almost completely absent from this sodic rim. Small irregular spots of more sodic oligoclase whose distribution is independent of the zoning are common within the grains. Myrmekite is common as small anhedral grains, ¼ to 1 mm, and as fringing overgrowths on tabular plagioclase crystals where microperthite is the adjacent mineral. More rarely the myrmekite appears to be a partial replacement of an earlier euhedral plagioclase.

Microcline and microcline-microperthite form inequant anhedral grains 1 to 5 mm in diameter. They appear to be localized on boundaries of other mineral grains and evidently have replaced all the other major minerals; even quartz was replaced. The myrmekite appears to be contemporaneous or younger than the microcline as it is rare except in association with potassium feldspar. The microperthite is generally characterized by minute blebs and wispy films of albite, which are more concentrated toward the centers of the grains. Somewhat coarser patch perthite is also present, however.

The quartz commonly forms aggregates that are as much as 15 mm in diameter and are composed of anhedral grains. Some of the aggregates tend to have a spheroidal or nodular form, whereas others are interstitial to the other minerals. Moderate undulant extinction and scattered trains of minute liquid inclusions are usually present. Very minute rutile(?) needles are abundant inclusions.

Biotite forms ragged anhedral to platy subhedral grains as much as 6 mm in diameter. It is pleochroic in pale straw yellow (X) and dark olive-brown (Y and Z). The index is 1.639. $2V(-)$ is estimated at 3°. Most of the biotite contains numerous inclusions of the accessory minerals.

Hornblende crystals, as much as 6 mm long, form subhedral to euhedral prisms. They are pleochroic: pale yellow (X), bottle green (Y), blue green (Z), with absorption formula, $X<Y<Z$. $\alpha=1.646$, $\beta=1.661$, $\gamma=1.668$, $2V$ (measured)$=64°(-)$, $Z \wedge c=19°$. Twins are common. The hornblende also contains numerous accessory minerals as inclusions and may show slight evidence of primary reaction to form biotite, and epidote or clinozoisite.

The accessory minerals include magnetite, apatite, sphene, zircon, allanite, and thorite, in order of decreasing abundance. The magnetite forms subhedral grains as much as 0.4 mm in diameter and is probably titaniferus. Sphene occurs as striking, large subhedral to euhedral grains as much as 2 mm long. Some smaller, ragged grains of sphene appear to be alteration products in biotite. Apatite and zircon are generally minute prismatic inclusions, 0.05 to 0.2 mm in length. The zircon is a zoned hyacinth variety, beautifully euhedral. The allanite is intimately related to scattered epidote grains and, like most of the accessories, is most abundant in association with the biotite and hornblende. A few large grains as much as 0.8 mm long have been observed as alterations in plagioclase. Thorite has not been identified in thin section but has been recognized in heavy-mineral separates.

The following table contains chemical, normative, and modal analyses of typical specimens of the granodiorite. For comparison, Johannsen's average of chemical analyses of 80 granodiorites (1932, v. 2, p. 344) is also given.

No specimens of the granodiorite have been observed that are completely free of so-called alteration minerals. Minerals of the epidote group are very common. Zoisite and clinozoisite aggregates replace plagioclase; epidote is an alteration of plagioclase, hornblende, and biotite; allanite is associated with the other members of the group. A late magmatic origin for most of these

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Analyses of granodiorite

	Johnny Lyon granodiorite [W. J. Blake, analyst]		Average of 80 granodiorites (Johannsen, 1932, v. 2, p. 344)
	1½ miles from contact (SW¼ sec. 33, T. 14 S., R. 21 E.)	2 miles from contact (SW¼ sec. 20, T. 14 S., R. 21 E.)	
Chemical analyses			
SiO_2	66.24	68.89	66.13
TiO_2	.50	.45	.51
Al_2O_3	15.83	15.02	15.50
Fe_2O_3	1.58	1.40	1.62
FeO	2.00	1.89	2.70
MnO	.08	.08	.07
MgO	1.75	1.43	1.73
CaO	3.89	3.44	3.70
Na_2O	3.89	3.84	3.55
K_2O	2.85	3.14	3.17
H_2O (total)	1.20	.88	.89
P_2O_5	.19	.17	.17
Others	----------	----------	.07
Total	100.00	100.63	99.90
Normative analyses			
Salic			
Quartz	21.25	25.02	
Orthoclase	17.79	18.35	
Albite	32.91	32.49	
Anorthite	17.18	14.46	
Femic			
Diopside	1.19	2.22	
Hypersthene	5.07	3.99	
Magnetite	2.30	2.09	
Ilmenite	.94	.91	
Total	98.63	99.53	
CIPW classification	I. 4. 3. 4	I. 4. 3. 4	
Modal analyses [Point counter method]			
Quartz	23.5	25.8	
Plagioclase	42.4	45.3	
Myrmekite	.8	2.0	
Microcline perthite	12.7	14.2	
Biotite	12.9	6.4	
Hornblende	5.6	4.0	
Ore minerals	1.4	1.3	
Sphene	.5	.6	
Apatite	.1	.2	
Zircon	.2	.1	
Allanite	.1	----------	
Total	100.2	99.9	
	3,865 points on 14 sq cm	3,734 points on 13 sq cm	

minerals seems probable. Where hydrothermal alteration has been most intense, and is most recognizable, the epidote group is rare or absent.

Chlorite is the major alteration mineral of biotite and hornblende. It is a penninite type and usually includes fine needles of leucoxene, epidote or clinozoisite, and iron oxides as coproducts of decomposition. These are often in oriented arrangement revealing the pseudomorphous nature of the alteration.

An illitic sericite and finer grained clay minerals pervasively replace as much as 50 percent of the plagioclase in many of the specimens examined. The sericite generally forms felty to oriented interlocking mats of very fine grained shreds (less than 0.05 mm) which give the plagioclase a semiopaque appearance. The fine-grain and gradational optical characteristics make estimation of proportions difficult but sericite appears to be the most abundant of these minerals.

Finely divided clay(?) minerals also give a faint cloudy effect to the microperthite, but it is largely free from alteration.

Limonite is a weathering byproduct which may be concentrated around magnetite and mafic minerals, or dispersed through the rock giving the rock its characteristic weathering hues.

The main phase of the pluton is generally uniform in mineral composition over the area examined, as shown by the following table which gives point-counter modes of specimens from widely separated points. The average rock may be classified according to Johannsen (1932, v. 2, p. 318–347) as a granodiorite, 227 P.

Modal analyses of samples of the main phase of the Johnny Lyon granodiorite

	Location and distance from present contact				
	SE¼ sec. 20, T. 14 S., R. 21 E., 1¼ miles	SE¼ sec. 6, T. 15 S., R. 21 E., 2½ miles	NW¼ sec. 8, T. 15 S., R. 21 E., 1½ miles	SE¼ sec. 21, T. 14 S., R. 21 E., 200 yd	SW¼ sec. 34, T. 14 S., R. 21 E., 200 yd
Quartz	30.4	24.9	21.3	26.1	22.5
Plagioclase	43.7	53.9	55.0	49.2	49.0
Myrmekite	.9	.7	2.1	1.3	1.1
Microcline-perthite	7.1	7.3	8.1	10.1	14.5
Biotite	12.5	8.6	7.3	10.6	11.5
Hornblende	3.4	2.0	3.1	Tr.	----------
Ore minerals	1.7	1.5	1.2	1.7	1.2
Sphene	.2	.6	1.4	.5	----------
Apatite	.2	Tr.	.1	.5	.1
Zircon	Tr.	.3	.1	Tr.	Tr.
Allanite	----------	----------	.3	Tr.	----------
Total	100.1	99.8	100.0	100.0	99.9

One interesting variation in the composition is the lack of hornblende in the ¼- to ½-mile wide border of the pluton against the Pinal schist. In addition to the last two specimens given in the table, five other specimens collected in this zone along the contact, from the Willcox-Cascabel road to southwest of Keith Ranch, contain only a trace of amphibole or none at all. Although not completely lacking, sphene appears to decrease in the marginal zone. The marginal facies of the granodiorite appears to grade into the main facies.

Euhedral crystals and replacement textures in the main phase of the granodiorite suggest the following sequence of crystallization: Tabular plagioclase and prismatic hornblendes were the first crystals to form; biotite succeeded the hornblende in the late stages of plagioclase formation; this in turn was followed by quartz crystallizing in aggregates; microcline perthite and myrmekite appear to be later than much and perhaps most of the quartz. The microcline perthite habitually occupies positions interstitial to all other major minerals, and it has replacement relations to all these minerals. The general localization of myrmekite on the contact between plagioclase and potassium feldspar suggests that it is either contemporaneous with or younger than the latter. Among the accessory minerals, apatite, zircon, and magnetite appear to have started crystallizing early in the sequence. Sphene crystallized both early and late. Epidote group minerals appear to have formed in late magmatic stages in part.

Deuteric and hydrothermal minerals, which can rarely be distinguished from one another, have replaced 2 to 40 percent of the original minerals in the specimens examined. The magnitude of these effects, particularly to the west and southwest of the Johnny Lyon Hills, suggests sweeping hydrothermal action. In many specimens the effects appear to have followed or accompanied Laramide shearing. However, there is also evidence for Precambrian hydrothermal alteration in three north-trending zones on or adjacent to the Mesa. These zones will be discussed in a later section.

HYBRID GRANODIORITE

Appreciable contamination of the granodiorite by the country rock is confined to the vicinity of metabasalt inclusions, described in the section on the Pinal schist. The hybrid granodiorite near these inclusions is variable in texture and composition. The amount of coarse prismatic hornblende is locally increased, and the amounts of potassium feldspar and quartz are decreased. The resulting rock approaches the composition of the most modified inclusions. Only by textural and structural criteria can hybrid inclusions be distinguished from hybrid host rock, and in many places the criteria are insufficient and inconclusive. Some dikes and irregular injections of normal uncontaminated granodiorite cut the hybrid rocks.

No contamination of the granodiorite is evident near inclusions of other rock types, which include rhyolite of Precambrian age and micaceous hornfels derived from the Pinal metasediments. Both these rock types appear to have been nearly in chemical equilibrium with the magma. The slight zoning of the pluton, with biotite preponderant over hornblende near the intrusive contact, may reflect some alumina contamination of the magma, but it might equally well reflect a local internal differentiation within the pluton.

APLITE AND PEGMATITE

Many aplite and pegmatite dikes cut the granodiorite, and even more abundant dikes and concordant sheets cut the adjacent schist. These bodies have not been distinguished from the granodiorite on the map because of their great number and generally small size. A few attain 600 to 800 feet in length and 40 to 50 feet in maximum width. Many excellent examples are to be seen in the contact zone of the Pinal schist north of the Johnny Lyon Hills.

Aplite and pegmatite occur separately and also associated with each other, perhaps as multiple injections into the same fissure. The contacts between aplite and pegmatite may be sharply defined or gradational, and no consistent sequence of intrusion is apparent.

The pegmatites are generally simple in composition and consist of blocky pink perthite; white to light-gray massive quartz; albite, commonly as the platy variety cleavelandite; and muscovite, locally in striking arborescent patterns intergrown with platy albite. Small crystals of black tourmaline and red garnet are uncommon accessory minerals. Zoning of the pegmatites is not conspicuous except for a few quartz cores. Pegmatite bodies within the Pinal schist are enriched in muscovite on their margins.

The aplites are of two types. A simple segregation type that forms small bodies within the granodiorite has a typical composition (estimated) of:

	Percent
Quartz	35
Oligoclase (An_{10-20})	40
Microcline microperthite	15
Biotite (or chlorite-epidote pseudomorphs)	10

This rock is fine grained and sugary textured, except for a few larger crystals of plagioclase similar to those in the granodiorite.

Larger aplite bodies, in well-defined dikes both in the intrusive body and in the wallrock, are medium grained and saccharoidal. The estimated composition of typical specimens is:

	Percent
Quartz	35
Oligoclase (An_{10-15})(myrmekitic)	25
Microcline	30
Muscovite	5–10
Garnet	2–3

The first type of aplite is usually as deeply altered, and to the same minerals, as the granodiorite. The second type is distinctly less altered, probably in part because it lacks biotite, which is susceptible to alteration.

HYDROTHERMAL ALTERATION ZONES

In addition to the pervasive alteration of the granodiorite already discussed, three nearly parallel bands of shearing and more intense alteration trend north to N. 15° E. on the Mesa. These bands, which are shown on the geologic map, are 100 to 400 feet in width and 2½ to nearly 5 miles in recognized length and dip steeply to the west. The bands probably originated in earlier Precambrian time, for the western and largest band seems to pass beneath the Apache group on the north and beneath the overthrust Paleozoic rocks on the south without affecting them. The eastern band, at its south end, enters the Pinal schist, and the schist-granodiorite contact is offset at least several hundred feet. Numerous lamprophyre dikes of Tertiary(?) age cut all the bands and are not displaced or more altered.

The alteration bands are characterized by a central shear zone, which is silicified locally, and a bordering envelope of altered granodiorite, which usually grades to normal granodiorite at the outer limits.

The shear zones, where not masked by silicification, are marked by cataclastic products ranging from massive-weathering, mylonitic augen gneiss to pulverulent breccia and gouge. The gneissic textures are generally restricted to bands a few feet in width, whereas tabular bodies of gouge as much as 100 feet wide are common. These cataclastic phases generally occupy a central position in the band, but some gouge zones occur locally with diverse attitudes in all parts of the band. The gneissic foliation, gouge zones, and silica bodies for the most part dip 50° to 70° W.

Silicification has produced large replacement bodies and also veins, from a small fraction of an inch to a few feet wide, commonly in anastomosing stockworks. The largest bodies, which are as much as 100 feet wide and a half a mile long, are composites of both types. The silica is massive milky-white to gray quartz. The quartz is commonly brecciated and recemented. It contains inclusions of partially silicified granodiorite and vugs lined with milky quartz crystals as much as 1 inch in length. Most of the quartz was concentrated in the central part of the shear zone, but some lenses are slightly oblique to the trend of the alteration band as a whole. The silicified lenses are resistent to erosion and as a result form low ridges and knobs. Abundant lenses in the western band evidently were a factor in localizing the drainage divide between the River Slope and the Mesa.

The sheared and silicified zones are generally bordered by intensely altered granodiorite, which grades outward into fresh rock. On the outer edge of this altered envelope, the granodiorite is limonite stained; the mafic minerals are largely chloritized; and the feldspars are dulled by sericite. Nearer the sheared and silicified zone, the plagioclase becomes darker and increasingly albitic. The most albitic phase, Ab_{95} has abundant inclusions of coarse sericite and none of the original zoning. With progressive alteration of the plagioclase, the microcline perthite develops a patchy perthitic texture and is stained by limonite; and the biotite and hornblende are completely replaced by chlorite, calcite, limonite, and leucoxene. Veinlets and masses of calcite and epidote are conspicuous in the inner part of the alteration envelopes; but where albitization of plagioclase was most extensive, epidote is uncommon or absent. Specular hematite and secondary copper minerals, dispersed and in veinlets, are present locally in the most altered areas.

Some of the most intense hydrothermal effects can be observed in an elliptical area of alteration half a mile north of the Johnny Lyon Hills and adjacent to the western alteration band. The rock is dark brown and is exposed over an area 1,000 feet long and 600 feet wide. The exposures suggest a pipelike form that plunges steeply to the south-southwest.

The texture closely resembles that of the unaltered granodiorite, but nearly all the quartz has been removed. The feldspar is dark brown but retains a fresh luster on cleavage surfaces. Numerous pockets of conspicuous yellow limonite are scattered through the rock. Under the microscope, the plagioclase is raggedly twinned unzoned albite (An_{2-5}). It contains a fine limonite dust and minute crystals of kaolinite(?). Most of the grains are tabular, 3 to 8 mm in diameter. The microcline forms a coarse patch perthite and is in large crystals. Myrmekite is absent. Two varieties of chlorite are present: (1) a coarse-grained pleochoric green penninite(?) and (2) a nonpleochroic very pale green prochlorite(?) in fine-grained colloform aggregates. The coarse chlorite is associated with leucoxene and limonite as pseudomorphs after the original mafic minerals. The fine-grained prochlorite(?) is intergrown with fine-grained albite, sericite, and limonite and has replaced an appreciable part of the rock. Only a trace of corroded quartz was observed. Sphene has been completely altered to leucoxene, and the apatite crystals appear to be corroded. An approximate mode of the rock follows:

	Percent		*Percent*
Albite	65	Sericite	2
Perthite	5	Leucoxene	1
Chlorite	25	Quartz	Trace
Limonite	2	Accessories	Trace

Though the alteration zones probably originated in Precambrian time, there is some evidence suggesting a second, possibly much later, passage of hydrothermal solutions through the zones. In and near the western band are a number of crosscutting veins of brown carbonate, quartz, and limonite boxworks. The veins are younger than small lamprophyre dikes which they intersect and are identical in mineralogy with some of the mineralized rock in post-Paleozoic fault zones. If the lamprophyre dikes are of Tertiary age, a probability which cannot be conclusively checked in this area, then a second (Tertiary) episode of hydrothermal activity is indicated.

CATACLASTIC PHASES

In the area west and southwest of the Johnny Lyon Hills, there are many zones of sheared granodiorite formed at least in part during the Laramide orogeny. Some of the most conspicuous zones are along the faults shown on the geologic map. Several of these faults are major thrusts that involve the Paleozoic rocks, whereas others have as yet no recognized relation to the major structural features. The zones are anywhere from a few inches to several hundred feet wide. The sheared rocks include mortar gneiss, augen gneiss, mylonite, massive breccia, and impalpable loose gouge.

Thin sections of the cataclastic rock reveal partial recrystallization to sericite, chlorite, and other low-temperature minerals. Some of this recrystallization is probably due to metamorphism during deformation, but some is later and presumed to be of hydrothermal origin. Minerals that have replaced previously crushed rock or occur in crosscutting veinlets include sericite, chlorite, quartz, and epidote. There is little evidence of associated base metals, though slight copper staining was noted in a small body of altered mylonite in a prospect pit in the NE¼ sec. 13, T. 15 S., R. 20 E.

GRANODIORITE BODY NEAR JOHNSON

Less than a mile southwest of Johnson, a lenticular body of granodiorite, 550 feet wide and 3,000 feet long, has been intruded into the Pinal schist. The body is concordant with the schist and is overlain unconformably by the Apache group at the northeast end. We have assigned the body to the Johnny Lyon granodiorite on the basis of general similarity in mineral composition and identical structural relation to the Apache group.

The granodiorite is a gray medium-grained rock with indistinct gneissic foliation parallel to schistosity and relict bedding in the adjacent schist. In hand specimens, plagioclase, quartz, and biotite may be seen. The composition, estimated from a single thin section, is 40 percent albite, 30 percent quartz, 15 percent orthoclase and 15 percent biotite, muscovite, magnetite, apatite, epidote, and chlorite. Cataclastic effects are conspicuous. The plagioclase is the only mineral that shows any idiomorphism, and it shows cataclasis. The crystals are locally bent, broken, somewhat turbid and replaced by granular quartz and small irregular patches of orthoclase. Quartz forms irregular aggregates of variable grain size, the larger grains commonly showing strain shadows. Orthoclase occurs in extremely irregular grains, commonly as interstitial filling in the quartz aggregates. Biotite and muscovite are in small crystals occurring singly and in clusters.

The shearing and foliation evidently date from earlier Precambrian time, for they are truncated by the pre-Apache unconformity and are lacking in the overlying Apache group. The parallelism of foliation in granodiorite and adjacent schist and the concordance of the granodiorite body as exposed are features not displayed by the Johnny Lyon granodiorite pluton and suggest that the small body may be an older intrusion emplaced before or during the Mazatzal revolution. On the other hand, the small body could be contemporaneous with the main pluton, and the conformable shearing in it could be due to the same Precambrian movements as the local discordant shearing in the main pluton. Unfortunately, the original petrographic details of the small body have been so masked by shearing and alteration that they are of little help in determining the correct interpretation.

ORIGIN

The Johnny Lyon pluton originated from the quiet intrusive emplacement of a large slightly discordant body of granodioritic magma into the Pinal schist, after the original deformation of the latter was nearly complete. There is only slight evidence of primary flow foliation, which the deep weathering of the granodiorite unfortunately tends to obliterate. From the orientation of scattered small tabular inclusions of schist and a few of the biotite plates, hornblende prisms, and tabular plagioclase, a steep flow foliation approximately parallel to the contact can be recognized at places. Some of the alinement among the larger metasedimentary inclusions may also reflect this flow direction.

The composition of the magma was originally granodioritic and was not strongly modified by reaction, as shown by its effects on inclusions and wallrocks. Among the several types of inclusions, only the metabasalt inclusions show strong reaction effects, and the compositional changes are predominantly in the direction of modification of the inclusions toward more silicic rocks. The hybrid magma is confined to the immediate vicinity of the inclusions and is minute in quantity compared to the mass of the granodiorite. The metarhyolite inclusions show every indication of recrystallization in a system near compositional equilibrium. The metasedimentary hornfels inclusions and contact zones, though considerably recrystallized and reconstituted, show only slight and very localized evidences of metasomatism, principally addition of potassium from the magma. The slight zoning of the pluton with biotite preponderant over hornblende near the intrusive contact may reflect some contamination of the magma by alumina, but it might equally well reflect a local internal differentiation within the pluton. The contacts between granodiorite and schist are sharply defined to within less than an inch in most exposures. There is no textural evidence suggesting assimilation, except possibly in scattered local injections of typical granodiorite along the marginal planar structures of the schist.

The mechanism of emplacement is not clear. Proponents of stoping might consider the numerous inclusions in the granodiorite significant, but volumetrically these inclusions constitute much less than 1 percent of the mass. Most of the stoped blocks would have to have been removed physically, from the visible scene at least, before they reached a reactive environment. Forceful emplacement under the drive of orogenic stress is not recorded by evidence of deformation that it would be reasonable to expect in the schist. The granodiorite itself shows no strong evidence of forceful flowage into place such as is common in syntectonic bodies.

Fusion in place at the base of the geosynclinal prism would be a reasonable source for the magma, but the metamorphic rank of the rock at the present site of the body shows that the schist was clearly never subjected to the geothermal gradients necessary to produce such effects at this level. Metasomatists would find little structural, textural, or compositional comfort in the geological relations.

The passive nature of the emplacement suggests a regional stress pattern with a minimum horizontal compressive stress, in which space was provided for the introduction of the magma without too much resistance, possibly under a gravity drive. The forces of the middle Precambrian deformation must have been greatly diminished or modified. An upward direction of relief is normally to be expected, but with the limited information on the shape of the pluton and the internal flowage, other directional relations of stress cannot be assumed.

AGE AND CORRELATION

The granodiorite of the Johnny Lyon Hills is one of many large bodies of postkinematic granitic rocks in Arizona that are truncated in erosional unconformity by the Apache group or its equivalent. The great mass of the Oracle granite (Peterson, 1938) at the north end of the Santa Catalina Mountains; the Madera diorite (actually a quartz diorite to granodiorite) and Ruin granite of the Globe region; and unnamed granite and granodiorite plutons in the upper Tonto Creek basin, the Grand Canyon, Morenci, and elsewhere are all potential equivalents, so are large igneous bodies at Jerome, Bagdad, and Chloride. All these bodies appear to record an episode of batholithic emplacement at the end of the pre-Apache orogeny.

Positive demonstration of equivalent ages must depend on extensive radioactive dating methods. A detailed study of the uranium-lead isotopic relations in zircons from several sample localities in the Johnny Lyon granodiorite indicates an age of crystallization of $1,660 \pm 30$ million years (Silver and Deutsch, 1961).

TUNGSTEN KING GRANITE

A large granite mass exposed in and near the Tungsten King mine is here named the Tungsten King granite. A small outcrop of granite in the Winchester Mountains and another in the Dragoon Mountains are also shown as Tungsten King granite on the geologic map. The grouping is convenient for cartographic and descriptive purposes; but the correlation is very tentative, and the three masses will be described separately.

TUNGSTEN KING MINE AREA

The granite outcrop near the Tungsten King mine is roughly 1 by 3 miles and forms the central and steepest part of the west slope of the Little Dragoon Mountains. The exposure is in an upfaulted block or horst between the Tungsten King fault on the east and the South Camp fault on the northwest. Overlapping alluvium forms most of the western boundary. This alluvium, lamprophyric dikes, Pinal schist, and aplite associated in space with the granite are the only formations in contact with the granite mass.

Parts of the original intrusive contact with Pinal schist are exposed at the north and south ends of the mass between the bounding faults. The strike of bedding and foliation in the schist swings locally through as much as 45° of arc roughly parallel to the southern contact, but the contact is discordant and irregular in detail. A fairly flat southeastward dip is indicated by the trace of the contact on the topography, by the occurrence of large inclusions of schist, probably roof pendants in the marginal part of the granite, and by the presence of several small outliers of granite in canyons south of the main mass. The abundance of aplite around the southern end of the mass is regarded as another indication of the presence of granite at moderate depth. Too little of the northern contact is exposed to determine its attitude.

The geologic relations do not permit close dating of this granite. It must be younger than the Pinal schist, which it invades, but older than the aplite, lamprophyre, and Tungsten King fault, which cut it. The Tungsten King fault is of Late Cretaceous or early Tertiary age, for it offsets thrust faults that cut Lower Cretaceous rocks, but is cut by Tertiary aplite dikes associated with the Texas Canyon quartz monzonite; thus the granite could have been intruded at any time between early Precambrian and early Tertiary. It is older than the Texas Canyon quartz monzonite because it is cut by regional faults, whereas the quartz monzonite was intruded across or along such structural features. In the upper part of Granite Canyon, aplite dikes near the granite contact are offset a few feet to a few score of feet by faults dipping only 5° to 20° If these low-dipping faults are related to the major overthrusts of the region, the aplite—and presumably the granite also—was emplaced before the Late Cretaceous or early Tertiary orogeny. The Texas Canyon quartz monzonite is younger than this orogeny. Our assignment of the Tungsten King granite to the Precambrian is of course tentative. The granite in the Winchester Mountains is certainly Precambrian; but that on the northwest side of the Dragoon range has been dated by Gilluly (1956, p. 93) as post Early Cretaceous, prethrust.

The granite in the vicinity of the Tungsten King mine is a medium- to coarse-grained light-gray rock, which weathers pale brown. Clear gray quartz, flesh-colored potassium feldspar, pale-green plagioclase, and black biotite are easy to distinguish in hand specimen. Both varieties of feldspar tend to show crystal outlines. Zoned phenocrysts of potassium feldspar as much as 4 cm long occur in places.

The mineral composition estimated in thin section averages about 25 percent quartz, 50 percent potasium feldspar, 20 percent palgioclase, 4 percent biotite and muscovite, 1 percent accessory magnetite, apatite, zircon, and sphene. The variations from the average are slight.

The plagioclase is typically in subhedral grains 1 to 10 mm long. It is albite (An_{5-10}) in all thin sections examined, but it contains abundant coarse sericite and some granular epidote; the presence of epidote suggests a more calcic composition originally. Narrow clear rims free from sericite and epidote are commonly conspicuous. Most of the potassium feldspar is microcline with coarse perthitic blebs and streaks of albite. Much of the microcline is in anhedral grains 2 to 4 mm in diameter, but some is in euhedral phenocrysts as much as 4 cm long. Small inclusions of plagioclase and less commonly of quartz and biotite are common. There is a tendency for plagioclase inclusions to be arranged parallel to the crystal faces of the microcline phenocrysts. The biotite is in 1-mm books or, more commonly, in tiny flakes that are aggregated in lenses averaging about 2 mm in diameter. Most of the biotite is green, but some is olive brown. It is replaced in part by aggregates of epidote, chlorite, and secondary sphene. Some muscovite, perhaps formed by crystal-for-crystal replacement of biotite, is invariably present. The quartz is in 1- to 4-mm grains which are clearly interstitial to plagioclase and less clearly interstitial to other minerals.

All thin sections show cataclastic effects. The quartz is strained and in places shows well-developed mortar structure. The biotite books are bent and broken. Fractures, in places marked by microscopic seams of quartz and calcite, cut the other minerals.

WINCHESTER MOUNTAINS

The granite that crops out in the northeastern corner of the Dragoon quadrangle is part of the basement on which the Galiuro volcanics rest. A major fault, regarded as a thrust fault, separates the granite from overturned limestone beds of Mississippian and Pennsylvanian age. North of the Dragoon quadrangle, the granite extends at least 3 miles northwestward into the Winchester Mountains along the west side of Severin Canyon, in a horst block about 1 mile wide, bordered on the two sides by the Galiuro volcanics. The continuity of the granite outcrop is broken at two places in the horst by transverse fault slices of steep-dipping limestone of Paleozoic age. About a mile north of the northernmost slice, the granite intrudes the Pinal schist; and at several places in the western wall of the canyon, it is overlain unconformably by the Bolsa quartzite. The dip of the Bolsa is gentle and suggests that all the exposed granite may have been within 1,000 feet of the pre-Bolsa unconformity. The relations prove that the granite was intruded in Precambrian time, presumably during the same intrusive epoch as the Johnny Lyon granodiorite. Correlation with the granite near the Tungsten King mine is at best very tentative.

The granite is medium to coarse grained and is pale brownish red in outcrop and on freshly broken surfaces. All outcrops are deeply weathered and so decomposed it is difficult to obtain a coherent hand specimen. Red potassium feldspar is the most abundant and conspicuous constituent throughout the rock; and it forms a few phenocrysts as much as 3 cm in diameter. Gray glassy quartz, dull white or green altered plagioclase, and in places chloritized biotite are the other constituents to be seen in hand specimen. The red color and decomposed state of the rock make it easy to distinguish in the field from the hard gray granite near the Tungsten King mine, but these obvious differences probably are due mostly to differences in the type of alteration.

The same primary minerals and gross textural features are seen in the rock from the two localities, but some differences in the proportions and characteristics of the primary minerals and considerable differences in the alteration products have been noted in thin section. Potassium feldspar makes up about half of both rocks, but in the Severin Canyon rock it is mostly orthoclase rather than microcline, and perthite is less abundant and generally finer textured. The phenocrysts are not appreciably zoned nor is there any tendency for inclusions to be oriented parallel to the crystal faces of the host. The quartz content ranges from 25 to 40 percent, and there is an inverse variation in the amount of plagioclase (An_{10}). On the average, biotite is probably slightly less abundant and apatite and opaque minerals slightly more abundant than in the rock near the Tungsten King mine.

The Severin Canyon rock is invariably much altered, but epidote, which is a conspicuous alteration product near the Tungsten King mine, was not formed. Much of the plagioclase is completely altered to sericite and probably clay minerals. Much of the biotite is completely chloritized. The orthoclase is generally much fogged by dusty alteration products. Red iron oxide in the dust and also in microscopic seams evidently is responsible for the color of the mineral in hand specimen. Hematite, or limonite, has partially replaced magnetite, and leucoxene occurs in lieu of sphene.

The alteration suggests chemical weathering but is much more pervasive than the weathering of other granitic rocks of the region. Recent weathering was probably superposed on weathering in Tertiary and Precambrian time. The exposed granite was not far below the unconformity at the base of the Galiuro volcanics. It was also not far below the unconformity at the base of the Bolsa quartzite. Deep weathering below the pre-Bolsa unconformity is indicated by the alteration of Precambrian diabase sills (p. 42), and petrographic evidence suggests an early origin for the pervasive alteration of the granite. Thin sections show that the rock was broken by fractures along which there was some microscopic brecciation. Narrow seams of calcite, chlorite, and locally quartz were formed by filling and replacement along the fractures. Where the fractures cut plagioclase, they are bordered by a band of clear albite, which grades outward within 1 mm into the intensely altered plagioclase which is characteristic of the rock. Evidently the fracturing and albitization followed the pervasive alteration. If the late fracturing and albitization are Laramide, as seems probable, the pervasive alteration must be older.

DRAGOON MOUNTAINS

About 3 miles southeast of Dragoon, sheared granitic rock crops out on the west side of the Dragoon Mountains, between Pinal schist on the east and overlapping alluvium on the west. The contact with the schist is a reverse fault; but a short distance south of the Dragoon quadrangle, near the mouth of Jordan Canyon, the rock clearly invades the Pinal schist. Gilluly (1956, p. 93) reported that about a mile farther south a small body of similar rock definitely intrudes the Bisbee group. The western contact of both bodies is a fault that Gilluly can date with assurance as older than the Stronghold granite, and thus fix in the same general epoch of deformation as the major thrusts of the Dragoon range. He correlated the two intrusive bodies and concluded that both are either Late Cretaceous or early Tertiary in age.

If the particular granite mass that extends into the Dragoon quadrangle is Late Cretaceous or early Tertiary, our tentative extension of the name Tungsten King granite to this mass, and also to the granite of Precambrian age in the Winchester Mountains, groups rocks of very different age. It is possible, however, that the mass in the southeastern corner of the Dragoon quadrangle is Precambrian. The evidence for a younger age is found in a different mass.

The granite in the Dragoon quadrangle is pale buff on weathered surface and light greenish gray on fresh fracture. Brecciation and shearing have resulted in considerable variation in texture, but not in distinct foliation. The average grain size is about 2 mm, but broken crystals of microcline as much as 15 mm long occur here and there. The minerals distinguishable in hand specimen are microcline, quartz, muscovite, biotite, and plagioclase. Microcline is the most conspicuous and abundant constituent. The biotite content, which is at most a few percent, is extremely variable and is negligible in most specimens. Tiny muscovite flakes are disseminated through the rock and are concentrated along fractures.

In thin section it is estimated that 40 to 50 percent of the rock is microcline; and most of the remainder is quartz and plagioclase in nearly equal proportions. The mica content is generally less than 3 percent. The microcline is perthitic, but the intergrown albite is less abundant and in smaller stringers than in the rock near the Tungsten King mine. The plagioclase is albite (about An_5) and contains abundant inclusions of coarse sericite or muscovite. The original texture is largely obscured by granulation and recrystallization, but the original subhedral form of the plagioclase is recognizable in some specimens. Muscovite occurs along lines of rupture and in small books between the other rock constituents. Small flakes of green biotite are widely but sparsely scattered through the broken-up parts of the rock.

The small outcrop of sheared and partly reconstituted granite in the Dragoon quadrangle corresponds to but one facies of the more extensive exposures farther south. There Gilluly (1956, p. 93) noted a relation between the amount of deformation and the amount of biotite. He estimated the biotite content of the least deformed parts of the masses as perhaps 5 percent or even more, whereas the more deformed parts contain only minor amounts of this mineral and resemble alaskites and aplites. He inferred from this that the original dark minerals of the rock were partially leached out in zones of greatest crushing. In describing the biotite-rich facies, he stated (Gilluly, 1956, p. 94), that the biotite—

forms clumps associated with muscovite, probably representing a former dark mineral that has been destroyed and partly reconstituted, and also makes well-formed crystals that are strung out along cracks through all the other minerals except epidote. The biotite along these cracks is not oriented parallel to them. It appears, from its intergrowths with the other minerals, association with water-clear albite that contains large crystals of muscovite and from the general suggestions of crystal growth within the rock, to be reconstituted from older chlorite. Presumably the plagioclase of the rocks was sericitized at the same time that the dark minerals were altered to chlorite. The chlorite thus formed was probably recrystallized into biotite at the same time that the sericite in the plagioclase was aggregated into muscovite. This recrystallization was probably caused by the intrusion of the Stronghold granite * * *. A little epidote is present in veins that cut all other minerals.

A complex history of shearing, partial leaching of dark minerals, chloritization and sericitization, and finally metamorphism by younger granite is a reasonable interpretation of the outcrops in the Dragoon quadrangle. These outcrops would correspond to the alaskitic- and aplitic-appearing facies of Gilluly. The supposed origin is such that rocks originally different would become similar in appearance. A highly variable amount of biotite would be present regardless of the identity of the original dark mineral which was destroyed. The plagioclase content is not likely to have been affected, however, and is therefore a clue to original differences. Gilluly found that plagioclase only locally makes up as much as 10 percent of the rock in the southern area, whereas 20 to 30 percent is typical of the specimens studied from the Dragoon quadrangle. This suggests an original difference in composition and possibly in age. In observed plagioclase content, the exposures in the Dragoon quadrangle are not significantly different from those near the Tungsten King mine with which we have tentatively correlated them.

APLITE ASSOCIATED WITH THE TUNGSTEN KING GRANITE

uch aplite is found near the intrusive contacts of Tungsten King granite west of the Tungsten King t (pl. 1). The aplite occurs as dikes and irregular intrusive masses in the marginal part of the granite and in the adjacent Pinal schist. The largest masses of aplite have at least one contact with the schist, and those that are mostly in granite contain large schist inclusions that probably represent roof pendants. Some small bodies of aplite occur in schist nearly three-quarters of a mile south of the nearest exposed granite, but they are probably much closer in depth because of a fairly gentle southeastward dip of the granite contact.

The aplite is regarded as a late differentiate of the Tungsten King granite because of association in space and similar relation to the Tungsten King fault, which bounds the granite and zone of aplite on the east and cuts off two dikelike apophyses of an aplite body a quarter of a mile south of the Tungsten King mine. The aplite is clearly older than the Tertiary(?) aplite which is associated in space with the Texas Canyon quartz monzonite and which cuts the Tungsten King fault. Our assignment to the Precambrian is very tentative, as it is for the Tungsten King granite.

The aplite is a sugary-textured white rock very similar in appearance to the aplite of Tertiary(?) age. The average grain size is about 0.5 mm. Quartz, potassium, feldspar, and a little muscovite are distinguishable under a hand lens. Some outcrops are cut by many minute quartz-filled fractures. These seams are the only basis for distinguishing the rock from the Tertiary(?) aplite in outcrop or hand specimen. The separation of the two formations on the map was made on the basis of geographic position with respect to a narrow zone free from aplite along Sheep Wash. Aplite bodies south of this zone were assigned to the Tertiary(?) aplite; and those to the north, to the older aplite.

The principal minerals and their proportions are approximately the same in the two aplite formations. Quartz and microcline are the most abundant minerals, making up perhaps 75 to 80 percent of the rock. The remainder is mostly albite, which is unaltered in the Tertiary aplite but somewhat sericitized in the older aplite. In some specimens the sericite has grown into fairly large individuals leaving a water-clear base of nearly pure albite. Muscovite is probably less abundant on the average than in the Tertiary(?) aplite, and some of it occurs on shear fractures that cut the other minerals.

PRE-APACHE GROUP UNCONFORMITY

The Apache group rests on an erosion surface of low relief which bevels structural features of the Pinal schist and ancient igneous intrusions. At some places, the Pinal schist is darker and apparently more siliceous near the unconformity—possibly because of deep weathering in pre-Apache time. The mineralogy of the dark schist was not investigated by study of thin sections. The Scanlan conglomerate, which is the basal formation of the Apache group, consists of very imperfectly rounded fragments, mostly of vein quartz. As Ransome (1903, p. 30–35) pointed out, the material composing it appears to be of local derivation and to represent the surficial detritus of an ancient plain slightly reworked by wave action.

UPPER PRECAMBRIAN ROCKS

APACHE GROUP

The name Apache group was proposed by Ransome (1903, p. 28) for the sedimentary rocks lying unconformably above the Precambrian crystalline complex and below the limestone of Devonian age in the Globe district. He later (1915a, p. 380–385) recognized the group in the Ray quadrangle, where the constituent formations were more fully defined.

The geologic map of Arizona (Darton and others, 1924) shows exposures of the Apache group extending south into the Santa Catalina Mountains about 15 miles northwest of the Dragoon quadrangle. The lower formations of the group were later recognized and mapped by Cook [4] near the Seven Dash Ranch, in the Little Dragoon Mountains. The group is represented in other parts of the Little Dragoons and in the Johnny Lyon Hills to the west and northwest. Near the south end of the Winchester Mountains, in Severin Canyon about a mile north of the Dragoon quadrangle, all the formations of the Apache are missing; and the younger Bolsa quartzite rests directly on earlier Precambrian granite. The Bolsa quartzite rests directly on the Pinal schist in the Dragoon Mountains in the southeastern corner of the quadrangle (pl. 1). The Apache group has not been reported in any of the ranges still farther south or east.

DIVISIONS

The following table gives the divisions and general character of the Apache group in the type area and, for comparison, the part of the group found in the Little Dragoon Mountains. The units preserved after pre-Bolsa erosion in the Little Dragoons are comparable in thickness to analogous units in central Arizona. The strong lithologic similarities of the various units support the idea that there was no great difference in source areas and sedimentary environments. The southern margin of deposition of the Apache group was probably some distance south of the Little Dragoon Mountains, and the group was removed by pre-Bolsa erosion.

[4] Cook, F. S., 1938, The geology of the Seven Dash Ranch area, Cochise County, Arizona: Arizona Univ. M.S. thesis, on file at Arizona Univ. Library, 26 p., maps.

Comparison of Apache group in Globe-Ray area and Little Dragoon Mountains

Divisions (Ransome, 1916, pl. 25)	Globe-Ray area (Ransome, 1916, pl. 25)	Little Dragoon Mountains
Troy quartzite	Generally pebbly crossbedded quartzite with lenses of conglomerate. Shaly rusty beds with worm casts at top. Thickness 400 ft.	In part equivalent to Bolsa quartzite. Thickness 20 to 335 ft.
Vesicular basalt flow	Thickness 25 to 75 ft	Absent.
Mescal limestone	Thin varicolored, more or less dolomitic beds with conspicuous cherty layers. Thickness 225 ft.	Absent.
Dripping Spring quartzite.	Fine-grained varicolored arkosic quartzite, much of it with dark-red and gray banding. Partings between beds not distinct. Ripple marks. Thickness 450 ft.	Fine- to medium-grained arkosic quartzite. Generally pink with color and grain-size banding. Thickness 300 ft.
Barnes conglomerate	Thickness 10 to 55 ft	Conglomerate 3 to 15 ft thick underlain locally by as much as 50 ft of arkosic quartzite like the Dripping Spring. Thickness 3 to 60 ft.
Pioneer shale	Maroon shale, arkosic and quartzitic near base. Thickness 150 ft.	Light - purple - banded siltstone with a few sandstone or quartzite beds especially near the base. Thickness 150 to 300 ft.
Scanlan conglomerate	Thickness 0 to 15 ft	Thickness 0 to 30 ft.

AGE

For many years Ransome (1903, p. 38–39; 1916, p. 164; 1923, p. 5) classified the whole Apache group as Cambrian, largely because of some lithologic similarity of the Mescal and Abrigo limestones. Darton (1925, p. 36; 1932, p. 319), on the other hand, contended that the pre-Troy formations were equivalent to the Grand Canyon series, long referred to the Algonkian. Ransome (Ransome and others, 1932, p. 5–6) subsequently appears to have accepted this conclusion for he wrote: "It has become increasingly probable during recent years that this restricted Apache group is generally equivalent to the Unkar group, the lower of the two divisions into which Walcott divided the supposedly Algonkian rocks of the Grand Canyon." He classified the Troy quartzite as Cambrian(?) and correlated it with the Bolsa quartzite (1932, pl. 3). Stoyanow (1936, table 2, and p. 473) likewise correlated the Troy with the Bolsa but provisionally correlated the restricted Apache group with the Chuar group, the younger of Walcott's divisions of the Grand Canyon series. We refer the formations of the Apache group in the Dragoon quadrangle simply to the upper Precambrian.

In recent years nearly all students of Arizona geology have removed the Troy quartzite from the Apache group and regarded it as Cambrian because (1) Cambrian fossils have been found in what has been regarded as the upper part of the formation; (2) the base of the Troy is clearly an unconformity which is irregular at many places and is definitely angular at one place in the Mescal Mountains (Darton, 1925, fig. 76A); and (3) in the Mescal Mountains the Troy overlaps the underlying formations to rest unconformably on the

Mescal limestone, Dripping Spring quartzite, diabase that intrudes these units, and finally on lower Precambrian granite (Darton, 1925, p. 34, fig. 76).

Recently Lochman-Balk took the position that the Troy should be restored to the Apache group for she stated (Lochman-Balk, 1956, p. 539):

From the vicinity of Winkelman, Ariz., northward to the Sierra Ancha Range a broken veneer of the transgressive Cambrian sandstone lies with apparent conformity upon the pre-Cambrian Troy quartzite of the Apache group. The Cambrian sandstone consists of medium to thin beds of fine-grained quartzite, pebbly at the base, overlain by thin, slabby quartzites, yellow to brown stained, with olive-green shale partings. *Scolithus* borings are not uncommon. The thickness varies from under 50 feet to over 250 feet. The apparent conformability and the similarity of material (since the Cambrian sands were obviously derived from the underlying quartzites) has caused the Cambrian sandstones to be confused with and often included in the Troy quartzite during local mapping. And it has become customary to call Cambrian sandstones the Troy quartzite following the practice of Darton (1925), although it should be noted that Darton when speaking of the fossiliferous Cambrian sandstones used the name "Troy." Actually the late Middle and Upper Cambrian sands of this entire area should be kept distinct from the underlying Precambrian Troy quartzites and should be named the Bolsa quartzite since it is the northward extension of the same lithic unit.

The Troy problem must be solved in areas north of the Dragoon quadrangle, but it has an important bearing on our correlations of the Bolsa quartzite and pre-Bolsa diabase sills. (Since this report was written, the Bolsa quartzite has been redefined to include some of the rocks formerly assigned to the Troy quartzite. The Troy has been restricted to the underlying Precambrian quartzite above the Apache group (Krieger, 1961)).

SCANLAN CONGLOMERATE

The basal formation of the Apache group is the Scanlan conglomerate, named by Ransome (1903, p. 30–31) for Scanlan Pass in the Globe quadrangle. It is described as 1 to 6 feet of subrounded quartz pebbles and a few schist fragments in an abundant sandy matrix of potassium feldspar and quartz. It rests on Pinal schist and granite.

In the Dragoon quadrangle the Scanlan conglomerate and overlying Pioneer shale are generally coextensive with the Paleozoic formations from the northwest corner of the quadrangle southward into the Johnny Lyon Hills, and southeastward as far as the Texas Canyon quartz monzonite stock.

The Scanlan conglomerate in the Dragoon quadrangle is characteristically an ill-sorted aggregate of imperfectly rounded pebbles of white vein quartz, and subordinate quartzite, schist, and jasper fragments, in an abundant matrix of sand and grit. (See fig. 4.) The pebbles range from ¼ to 8 inches in diameter, but

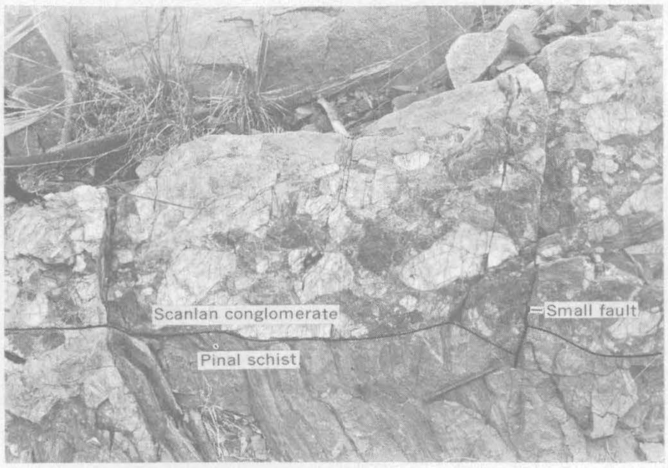

FIGURE 4.—Outcrop of Scalan conglomerate in the Little Dragon Mountains. Pinal schist exposed beolw conglomerate, quartzite at base of Pioneer shale above conglomerate. Pencil at lower right gives scale.

pebbles more than 4 inches in diameter are scarce. The matrix material locally contains as much as 20 percent detrital feldspar and is generally cemented by silica.

The conglomerate varies abruptly in thickness and lithology. In the most typical sections it is 1 to 3 feet thick and grades upward into pebbly quartzite at the base of the Pioneer shale. At some places the conglomerate attains a thickness of 20 feet. At others, it is absent altogether, and the quartzite of the Pioneer rests directly on the older rocks. At still other places the Scanlan is represented by as much as 30 feet of alternate conglomerate and quartzite in beds 1 inch to 3 feet thick. At such localities the very basal bed may or may not be conglomeratic.

The conglomerate is generally white or buff with tones of greenish gray, purple, or red. In the vicinity of the Seven Dash Ranch, the conglomerate is intercalated with and overlain by purple sandstone marked by scattered buff-colored spots about half an inch in diameter. In most other parts of the quadrangle, the conglomerate is associated with vitreous nearly white quartzite.

The following section was measured in a wholly unmetamorphosed area and shows the gradation between the Scanlan conglomerate and the Pioneer shale. Because of this gradational relation and the thinness of the conglomerate, the two formations are shown as a single unit on the geologic map. They are interpreted as representing a single episode of continuous sedimentation in a sea transgressing a remarkably regular plain of erosion that truncated the older crystalline complex. The conglomerate and associated quartzite are the near-shore transgressive facies, and the overlying shale is a facies deposited farther from shore.

Section showing gradational relation between Scanlan conglomerate and Pioneer shale

[Measured a quarter of a mile north of the Seven Dash Ranch (SW¼ sec. 16, T. 15 S., R. 22 E.)]

	Feet
Pioneer shale (in part):	
Shale, purple, siliceous; with quartzite interbeds 1 to 2 ft thick, exposed	10
Sandstone, purple; marked by buff spots; scarce scattered pebbles, mostly near base	49
Conglomerate lens, pale grayish-purple; with angular pebbles as much as 2 in. in diameter	1
Sandstone, purple; marked by buff spots, scattered pebbles, and thin lenses of conglomerate	29
Scanlan conglomerate:	
Conglomerate, buff; with angular pebbles of quartz, quartzite, and schist in coarse sandy matrix; top 1 ft purple and gradational into overlying bed	4
Angular unconformity.	
Pinal schist:	
Sericite schist and metagraywacke.	

PIONEER SHALE

The Pioneer shale was named by Ransome (1903, p. 31) for exposures at Pioneer, an old mining camp south of Globe. It was described as dark-reddish-brown arenaceous shales, which are thin bedded, exhibit characteristic, round or elliptical buff spots, and contain a few interbeds of fine-grained quartzite. Ransome (1916, p. 136) has remarked that elsewhere the Pioneer shale generally contains basal arkosic quartzites ranging from 15 to 175 feet in thickness.

Where unmetamorphosed, the Pioneer shale is easily eroded and, as a result, forms valleys and the lower slopes of hogbacks and cuestas. It gives rise to smooth topographic surfaces which are generally covered by soil and slide rock. Where metamorphosed, the formation is more resistant and forms some prominent peaks like the sharp hill half a mile south of the Republic mine and several unnamed peaks south of Lime Peak. Quartzite beds in the lower part of the formation form bold outcrops and cliffs in the western part of the area.

The unmetamorphosed facies consists of purple shale or siltstone, which contains scarce interbeds of gray quartzite as much as 2 feet thick, and a basal member of medium- to coarse-grained sandstone or quartzite. The shale is silty in texture and not very fissile. Rounded grains of quartz and minute glistening flakes of mica are commonly seen in it. Color banding parallel to the beds is characteristic and consists of alternating light and darker purple bands ⅛ to ½ inch thick. The sandstone and quartzite are feldspathic in varying degrees. Near the Seven Dash Ranch, 40 to 80 feet of coarse purple sandstone lies at the base of the shale. Farther south and west this unit is represented by nearly white quartzite. Southeast of Johnson Peak the unit thins to about 13 feet and contains interbedded shale. In the western half of the quadrangle, it is a conspicuous feldspathic quartzite that reaches a maximum measured thickness of 88 feet south of Kelsey Canyon in the northwest corner of the quadrangle.

The Pioneer shale of the area is characterized by distinctive spots of two types. The first type is the kind noted by Ransome (1903, p. 31) and Darton (1925, p. 29–30) and consists of round or oval buff-to-white areas about half an inch in diameter, apparently formed by reduction and removal of iron about a small nucleus. These spots occur in both siltstone and purple sandstone beds. Spots of the second type, noted particularly in argillaceous beds in the western part of the area, are black and either rounded or elongated parallel to the beds. They are ¼ to ½ inch in diameter or thickness and locally are as much as 2 feet long. The spots appear to be due to a manganese oxide stain. Both color markings are three dimensional and are not confined to outcrop surfaces.

The effects of metamorphism are more apparent in the Pioneer shale than in most of the other formations. As the Texas Canyon quartz monzonite is approached, the shales gradually pass from purple to ash gray, the color change starting as much as a mile from the intrusive contact. Cleavage oblique to the bedding is evident about half a mile from the contact, but color banding is retained and reveals the attitude of the beds. Seams of quartz parallel to the beds and disseminated cubes of pyrite were noted in this facies half a mile west of the Republic mine. Several hundred yards from the intrusive contact, the color banding disappears; and the rock grades into mica schist, which commonly has dark spots about an inch in diameter that appear to be fine-grained aggregates of dark-colored silicate minerals. This facies resembles parts of the Pinal schist and may have been mistaken for it in small isolated outcrops.

The Pioneer shale in the Dragoon quadrangle ranges from 150 to about 300 feet in thickness. A representative section follows.

Section of Scanlan conglomerate and Pioneer shale

[Measured on ridge 4¼ miles northwest of Deepwell Ranch (NE¼NW¼ sec. 21, T. 21 E., R. 14 S.)]

	Feet
Bolsa quartzite (in part):	
Quartzite, brown, pebbly.	
Unconformity.	
Diabase sill	291
Pioneer shale:	
Siltstone, purple, banded; marked by buff spots; some interbeds of light-colored quartzite; ripple marks; beds ¼ to 6 in. thick	69
Covered	62
Siltstone like 69-ft unit above	85
Quartzite, pinkish-gray, medium-grained, arkosic; pebbles of quartz and quartzite as much as 1½ in. in diameter are dispersed and concentrated in small lenses; beds 3 to 30 in. thick; marked grain-size banding; some crossbedding	88
Total thickness of Pioneer shale	304

Section of Scanlan conglomerate and Pioneer shale—Continued

	Feet
Scanlan conglomerate:	
Conglomerate consisting of subangular pebbles of vein quartz in a gray arkosic matrix	2
Unconformity.	
Johnny Lyon granodiorite:	
Granodiorite, pink, coarse grained.	

BARNES CONGLOMERATE

The Barnes conglomerate was named by Ransome (1903, p. 31) for Barnes Peak in the Globe quadrangle. In the type area it is described as 10 to 15 feet of conglomerate, which lies on the Pioneer shale and is characterized by well-rounded pebbles—predominantly of quartzite but in part of red jasper and white vein quartz—in a matrix of arkosic grit. According to Darton (1925, p. 29) the formation is a persistent and easily recognized unit, which, although thin, is a very conspicuous feature in nearly all exposures of the Apache group in Arizona.

In the Dragoon quadrangle the Barnes is more restricted in distribution than the lower formations of the Apache group. Exposures are confined to the Little Dragoon Mountains, where the formation is almost continuous, except for faulting, from the vicinity of the Keystone mine near Johnson northwestward for about 5 miles to a pinchout 2 miles southeast of Deepwell Ranch. The formation occurs also in a small thrust remnant about a mile south of the Tungsten King mine but is not known at any other locality in the Dragoon quadrangle. The restricted occurrence compared with the Pioneer shale and Scanlan conglomerate is due to pre-Bolsa erosion.

Where the Barnes is present it is generally exposed at the base of escarpments formed by the Dripping Spring and Bolsa quartzites. Because the Barnes is thin and grades into the Dripping Spring quartzite, these two formations are shown as a single unit on the geologic map (pl. 1).

The Barnes conglomerate in the Little Dragoons ranges from 3 to 15 feet and averages about 5 feet in thickness; it is characterized by smoothly rounded pebbles of quartzite, vein quartz, and some red jasper in a matrix of arkosic sand or grit with grains of pink feldspar as much as a quarter of an inch in diameter. (See fig. 5.) At one place a pebble of fine-grained quartz conglomerate and another of granodiorite(?) were observed. The pebbles are generally less than 4 inches in diameter; the largest one found was 6½ inches in diameter. Much abrasion is indicated by their smooth, rounded outlines. Water sorting is evident by the alternation in a few places of conglomerate and arkosic sand beds and by grain-size gradation within single beds. Evidence of the direction of water currents at the time of deposition was noted at one place, where the great majority of pebbles are tilted upward to the southeast from the plane of the beds; this tilting indicates the current came from the northwest.

FIGURE 5.—Typical outcrop of Barnes conglomerate, east of Seven Dash Ranch.

The Barnes conglomerate is generally easy to distinguish from other conglomerate beds in the area. The Scanlan has angular rather than well-rounded pebbles. The conglomerate at the base of the Bolsa quartzite is less uniform than the Barnes and frequently contains fragments of Dripping Spring quartzite, which are distinctive and easily recognized. Where the basal conglomerate of the Bolsa is composed largely of reworked pebbles from the Barnes, as it appears to be in the western part of the quadrangle, the two formations are generally distinguishable by the matrix, which is arkosic in the Barnes and nonarkosic in the Bolsa.

In the area south of Johnson Peak, the Barnes conglomerate bed was deposited directly on the shale and interbedded gray quartzite of the Pioneer shale, but a later diabase sill now separates the two formations. Northwest of Johnson Peak the conglomerate bed is underlain by pink arkosic quartzite, which is unlike the quartzite interbeds in the shale but similar to the matrix of the conglomerate and generally indistinguishable from the overlying Dripping Spring quartzite.

At a few places, the quartzite below the conglomerate is slightly more massive and crossbedded than that above, but these characteristics are not persistent enough to distinguish it everywhere. The pink quartzite below the conglomerate is generally 25 feet thick or less but locally exceeds 50 feet in the area northwest of the Seven Dash Ranch. For mapping purposes it was considered a basal quartzite member of the Barnes because its outcrops cannot be distinguished from those of the Dripping Spring quartzite with which the Barnes was mapped.

The lithologic similarity of quartzite beds above and below the conglomerate suggests that the conglomerate does not mark an important unconformity. The base of the conglomerate bed is an irregular channeled surface but was nowhere seen to cut across more than 3½ feet of beds. These small irregularities could be due to local scour by the currents that deposited the conglomerate; they do not necessarily indicate a significant break in deposition. Whether the variations in thickness of the Pioneer shale are due to original differences or to pre-Barnes erosion can only be determined after detailed stratigraphic study covering a larger area.

DRIPPING SPRING QUARTZITE

The name Dripping Spring quartzite was proposed by Ransome (1903, p. 31–32) for quartzite lying between the Barnes conglomerate and the limestone of Devonian age in the Globe district. His (Ransome, 1915a, p. 380–385) later work in the Ray district showed that two quartzites in this stratigraphic interval are separated by about 255 feet of limestone, which had been incorrectly assigned to the limestone of Devonian age in the complexly faulted Globe district. Therefore, Ransome redefined Dripping Spring quartzite to cover the lower quartzite only and proposed the new names Mescal limestone and Troy quartzite for the upper formations. The name Dripping Spring quartzite is now always used in this restricted sense.

In the Dragoon quadrangle the Dripping Spring quartzite has the same distribution as the Barnes conglomerate, being confined to parts of the Little Dragoon Mountains. With the overlying Bosla quartzite, it forms prominent cliffs and ridges. The hard white or brown Bolsa generally forms the more spectacular cliffs at the summits, whereas the pink or pale-reddish-gray Dripping Spring forms lesser cliffs below it. There is an exception to this general rule in the quartzite ridge a quarter of a mile southwest of Johnson where the summit is Dripping Spring quartzite, which at this locality contains many quartz veinlets.

The Dripping Spring quartzite in most parts of the Little Dragoons is an easily recognized formation underlain conformably by the Barnes conglomerate and overlain unconformably by the Bolsa quartzite. It is generally a fine- to medium-grained feldspathic quartzite carrying so much pink feldspar that it is pink or rose-colored. Color bands, generally in shades of pink and less than a foot thick, parallel the bedding; fine-grained nearly black bands, ¼ to 2 inches thick, are common. Close inspection reveals grain-zize differences in adjacent beds and also grain-size gradation within individual beds. These characteristics are like those of the lower half of the formation near Ray (Ransome, 1916, p. 137–138). The following section is typical except for the top 26 feet, which is white to brown, apparently lacks feldspar, and has shaly interbeds. These unusual beds seem to grade into the normal feldspathic facies within a few hundred feet along the outcrop.

Section of Barnes conglomerate and Dripping Spring quartzite

[Measured half a mile southeast of Seven Dash Ranch (NE¼NW¼) sec. 21, T. 15 S., R. 22 E.)]

	Feet
Bolsa quartzite (in part):	
Conglomerate consisting of flat angular slabs of Dripping Spring quartzite as much as a foot long in dark-brown quartzite matrix; basal contact irregular.	
Unconformity.	
Dripping Spring quartzite:	
Quartzite, white to brown; contains reddish- to deep purplish-brown shaly beds, 2 to 24 in. thick, irregularly spaced	26
Arkosic quartzite; banded in shades of pink; a few black-weathering bands less than 2 in. thick; alternation of fine-grained and medium-grained layers common	167
Thickness of Dripping Spring quartzite	193
Barnes conglomerate:	
Conglomerate consisting of well-rounded pebbles as much as 6½ in. in diameter in coarse arkose matrix with pink feldspar	4½
Arkosic quartzite, pink; lower part massive and vaguely crossbedded; upper part indistinguishable from 167-ft unit above conglomerate	22
Thickness of Barnes conglomerate	26½
Covered slope, underlain by diabase sill.	

In the vicinity of Johnson the Dripping Spring quartzite loses its distinguishing characteristics and is hard to separate from the Bolsa in mapping. The feldspar grains lose their distinctive pink color. The colorless feldspar in inconspicuous and no feldspar can be detected in some outcrops. The color banding and finally even the grain-size banding also disappear toward the south. As the lower quartzite of the Bolsa loses its distinguishing characteristics also, it was necessary to infer the Dripping Spring-Bolsa contact between localities where the basal conglomerate of the Bolsa is exposed. Metamorphism caused by the Texas Canyon quartz monzonite is probably responsible for the facies change in the quartzite formations. The following section represents the metamorphosed facies and is much the thickest section of the Dripping Spring quartzite that was measured.

Section of Barnes conglomerate and Dripping Spring quartzite
[Measured half a mile west of Johnson (NW¼) sec. 26, T. 15 S., R. 22 E.)]

	Feet
Bolsa quartzite:	
Conglomerate; contains subangular quartzite boulders as much as 26 in. in diameter. Exposed thickness	14
Unconformity.	
Dripping Spring quartzite:	
Quartzite, reddish-gray; shaly seams along bedding planes	84
Quartzite, reddish-gray; banded arkosic beds in lower part; numerous quartz veinlets, mostly parallel to beds	220
Thickness of Dripping Spring quartzite	304
Barnes conglomerate:	
Conglomerate; consists of rounded pebbles of quartzite, vein quartz, and jasper, as much as 4½ in. in diameter, in matrix of coarse sand and white clay	9
(Metadiabase sill, green, with quartz veinlets, 66 ft)	
Pioneer shale (in part):	
Shale, gray, baked; quartzite interbeds as much as 12 in. thick; some disseminated pyrite cubes; quartz veinlets parallel beds.	

DIABASE SILLS

In the northeastern part of the Little Dragoon Mountains and immediately beneath the Barnes conglomerate, there is a diabase sill 40 to 140 feet thick. A lower sill 15 to 70 feet thick is separated from the upper sill by 3 to 50 feet of shale and quartzite. The two sills, which are shown as one at most places on the geologic map (pl. 1), are absent in the vicinity of Lime Peak, as are the Barnes conglomerate and probably the uppermost part of the Pioneer shale. Farther west, from Sheep Basin northwestward to Kelsey Canyon, diabase is found sporadically at the top of the Pioneer shale and beneath the Bolsa quartzite. At the only place where the Barnes is present in this area, a mile south of the Tungsten King mine, there are two sills, as in the northeastern part of the range. The diabase is moderately thick in the faulted syncline east of the Tungsten King mine, but it is thin and only locally present west of the South Camp fault and in the Johnny Lyon Hills. A large remnant appears in the latitude of Mesa Tank and thickens to 250 feet northward near Kelsey Canyon. What seems to be a part of this remnant is found in a thrust slice near the American mine.

As all occurrences of the diabase are at or near the same stratigraphic horizon and as all exposures of this horizon show diabase, we believe that diabase was once continuous over the area of outcrop. According to this interpretation, the present patchy distribution of the rock is due to pre-Bolsa erosion.

The diabase is very easily eroded and characteristically forms minor valleys and talus-covered slopes beneath cliffs and hogback ridges of the overlying quartzite. Quartzite debris tends to obscure the diabase, and its contacts generally cannot be located more closely than within 10 or 20 feet.

LITHOLOGY

In its freshest exposures the diabase is a medium- to fine-grained rock with ophitic texture and is generally a dark gray green. Near the center of the sills, the rock has altered feldspar laths as much as 7 mm long, but toward the margins it becomes aphanitic, and for an inch or two at the very edge, it commonly has a red chertlike selvage interpreted as devitrified glass. Although the original texture of diabase is still evident, the original minerals are largely or wholly destroyed. The plagioclase has been almost completely altered to kaolinite(?), fibrous gibbsite, and calcite; some traces of albite remain. Most of the original pyroxene has been replaced by chlorite, pale-green amphibole, calcite, and iron oxide dust, but scarce relics can be identified as augite. Brown biotite, partly altered to chlorite, is also present. Between 5 and 10 percent of ilmenite-magnetite, more or less altered to leucoxene or limonite, and a little apatite and zircon are characteristic. This phase of the rock is friable and decomposes rapidly into a dark red-brown soil.

Within the friable phase there are scarce small lenses of harder more resistant rock, which also has ophitic texture but is brown to reddish brown. The resistant lenses are commonly a little coarser grained than the adjacent rock. Albite laths, which contain much sericite(?), chlorite, and calcite, constitute about 65 percent. The original ferromagnesian mineral, which was interstitial and made up about 25 percent of the rock, is represented by yellowish birefringent serpentine(?), calcite, and other secondary products. Ilmenite-magnetite, partly replaced by leucoxene, makes up about 8 percent. There was a little primary sphene.

Lenses of distinctive red pegmatite a few feet thick were found in the diabase at several places. Hand specimens of the pegmatite are characterized by many very thin tablets of red feldspar 1 or 2 cm long, and skeletal poikilitic crystals of ilmenite, as much as 5 cm in diameter. The composition, estimated in thin section, is 60 to 70 percent orthoclase, 20 to 25 percent quartz, and 10 to 20 percent ilmenite-magnetite. Orthoclase, which is turbid because of red dustlike inclusions, forms large twinned and ragged tablets, and also smaller grains. The interstitial material is quartz and ilmenite-magnetite. In places the quartz is intergrown with orthoclase and has replaced it. Apatite as slender needles is a conspicuous accessory mineral.

In the northeastern part of the Little Dragoon Mountains, the top few feet of both sills contain amygdules of pink orthoclase, chlorite, and quartz. Very commonly the chlorite and quartz are confined to the centers of the amygdules, and the outer rims consist of dusty orthoclase in euhedral crystals with rectangular outlines. The same type of orthoclase forms veinlets cutting the diabase. Neither amygdules nor vesicles of any kind were found near the bottom of the sills although chilling at the base produced fine-grained rock like that near the top.

South of Johnson and elsewhere within about a mile of the Texas Canyon quartz monzonite stock, the diabase is further altered mineralogically and texturally. In the rare specimen showing the original texture, sericitization not clay alteration characterizes the feldspar laths. Green biotite is very abundant and, with quartz and some muscovite, commonly pervades the whole rock. Skeletons of magnetite, ilmenite, and leucoxene give the last indications of the original texture. Schistosity is generally well developed, and the resulting rock is a green schist somewhat resembling the amphibolite members in the Pinal schist but having biotite rather than amphibole as the principal constituent. The biotitic schist is easily distinguished from the adjacent formations of the Apache, which are quartzites, shales, or sericite schists wholly lacking in dark mica. The mineral association is not the customary one formed by metamorphism of diabase and indicates that the clay alteration was earlier and had removed lime from the rock before the later metamorphism took place.

INTRUSIVE ORIGIN

Although the remarkably constant stratigraphic position and amygdaloidal tops of the diabase bodies suggest they are flows rather than sills, compelling evidence for an intrusive origin was found half a mile northwest of the Seven Dash Ranch. At this locality, the arkosic quartzite for a few feet above the upper body contains abundant altered spots as much as 15 mm in diameter which are dark gray to rusty brown and are surrounded by rims 1 to 5 mm wide in which the quartzite is bright pink. In thin section the dark spots are a mosaic of quartz grains full of needles of tourmaline and interstitial specularite. The quartz grains of the mosaic have clear clastic cores surrounded by later overgrowths. Feldspar is lacking from the dark spots and is concentrated in the pink rims surrounding them. If the spots are a contact metamorphic effect as they certainly seem to be, the diabase must be intrusive. Also indicating intrusive origin are included quartz granules in the chilled upper selvage of the diabase and penetration of the overlying quartzite by diabase—mostly on a microscopic scale. One stubby apophysis several inches long was noted in the field.

The constant stratigraphic position of the sills is probably due to the relative competence of the rocks intruded. The magma rose through the Pioneer shale until it reached the more competent Barnes conglomerate and Dripping Spring quartzite where it spread out laterally. Where two sills are present, it is probable that the upper sill is slightly older and, by its presence and contact effects, has localized the other sill below it. No dikes or other possible feeders have been recognized.

AGE AND CORRELATION

The diabase is younger than the Pioneer shale and Barnes conglomerate into which it was intruded. It is older than the pre-Bolsa erosion surface, which cuts into and through the sills at many places. In the Johnny Lyon Hills-Kelsey Canyon area, where post-Apache metamorphism is at a minimum, a pre-Bolsa weathering profile on the diabase is evident beneath the Bolsa quartzite. The gray-green diabase becomes increasingly iron-stained toward the contact until it is deep red brown. The ophitic texture becomes less pronounced, and the rock grades successively to a massive hematite-cemented material and then to a fissile hematite-rich shale 3 inches to 1 foot thick. Resting directly on this shale are hematite-rich basal conglomerates and quartzites of the Balsa. The iron oxides in the basal part of the Bolsa and in the ancient soil have been converted to magnetite by later metamorphism in the Sheep Basin region. Pebbles of the distinctive red pegmatite from the diabase were found in the basal conglomerate of the Bolsa at one place. Thus it is clear that both the diabase and the pegmatite it contains are older than the Middle Cambrian.

We assign the diabase of the Dragoon quadrangle to the later Precambrian and correlate it with those diabases of central Arizona that Darton (1925, p. 34) described as unconformably overlain by the Troy quartzite.

Much diabase in central Arizona is clearly younger than the Troy quartzite, and there has been considerable difference of opinion as to the proper age assignment. In the Globe, Ray, and Miami districts, Ransome (1903, p. 86; 1919, p. 56) recognized that large masses of diabase were restricted to the Troy and older formations but found small masses of diabase intrusive into limestones of late Paleozoic age; therefore, he regarded all the diabase exposed there as of late Paleozoic or early Mesozoic age. Darton (1925, p. 254–255), on the other hand, regarded the main diabase intrusions as pre-Troy but recognized that some of them cut the lower part of that formation. He thought the dikes cutting Paleozoic limestones were feeders for basalt flows of Tertiary or Quaternary age. In recent detailed studies of the Globe-Miami district, Peterson (1954) found no evidence for more than one age or variety of diabase and assigned all the diabase to the Late Cretaceous or early Tertiary. Farther north in the Salt River Canyon area, however, Shride (written communication 1958) found that diabase intrudes the Troy and is overlain unconformably by fossiliferous Upper Devonian rocks. In the Vekol Mountains Carpenter (1948) found that diabase intrudes a lower member of the Troy and is overlain unconformably by a fossiliferous upper member. He is of the opinion that the diabase is of Early or Middle Cambrian age. The various age assignments are as follows:

Age assignment	*Locality*	*Reference*
Late Cretaceous—early Tertiary.	Globe, Miami	Peterson (1954).
Late Paleozoic—early Mesozoic.	Globe, Miami, Ray.	Ransome (1903, p. 86; 1919, p. 254–255).
Pre-Devonian	Sierra Ancha	A. F. Shride (written communication, Jan. 8, 1958).
Post-Middle Cambrian pre-Late Devonian.	Superior	Short and others (1943, p. 38).
Early or Middle Cambrian.	Vekol Mountains.	Carpenter (1948).
Late Precambrian	Central Arizona.	Darton (1925, p. 34, 254).
Late Precambrian	Dragoon quadrangle.	Cooper and Silver (this report).

The problem of the age of the diabase is fundamentally a problem of the age and correlation of the Troy quartzite. If beds of both Cambrian and Precambrian ages have been included in the Troy as Lochman-Balk contends (1956, p. 539), it is quite possible that there was only one episode of large diabase intrusions in Arizona—probably late Precambrian and certainly no younger than Middle Cambrian. Evidently there were some post-Cambrian diabase intrusions in the Globe-Miami area.

POST-APACHE—PRE-MIDDLE CAMBRIAN UNCONFORMITY

An important unconformity separates the Apache group from the Bolsa quartzite of Middle Cambrian age. Angular discordance is not evident in outcrops, but the regional stratigraphic relations indicate that the unconformity marks a considerable lapse of time during which the Apache group was consolidated, intruded by diabase sills, uplifted, and eroded. The Bolsa quartzite was deposited on an erosional surface having a maximum relief of about 300 feet. In much of the area, the surface was cut on the Apache group or the diabase, but at some places it was cut on the crystalline basement. In the northeastern part of the Little Dragoon Mountains, the Dripping Spring quartzite formed a low plateau in pre-Bolsa time and was cut by steep-sided valleys 150 to 200 feet deep and surmounted by hills as much as 100 feet high. The Bolsa quartzite filled the valleys and appears to have just buried the highest hills.

The above conclusions are based chiefly on the assumption that the Abrigo formation was deposited conformably on a horizontal surface of Bolsa and that variations in thickness of the Bolsa are, therefore, an accurate measure of the relief of the pre-Bolsa surface. This is the principle used in preparing figure 6 which shows the characteristics of the pre-Bolsa topography. Where it was impossible to complete the stratigraphic sections to the Bolsa-Abrigo contact, because of faulting or cover, correlation for figure 6 is based on the Barnes conglomerate or some other recognizable marker bed.

It is obvious that the conclusions are only as valid as the basic assumption and the accuracy of the stratigraphic thicknesses measured. There is no doubt about the conformity between the Bolsa and Abrigo. The contact between the two formations is exposed at many places in the area and is without exception gradational and certainly conformable. According to Ransome (1904, p. 31) it is a conformity at the type section at Bisbee. Of the area immediately south of the Dragoon quadrangle, Gilluly (1956, p. 16) wrote, "The contact of the Abrigo limestone with the underlying Bolsa quartzite is one of complete conformity and, indeed, in many localities is an entirely artificial division in a transitional series." It is possible that the contact, although conformable, was never strictly horizontal because of initial dip. Any initial dip would of course modify the conclusions, but it is unlikely that significant errors arise from this source. The chance of serious error is greater from errors in measurement of the sections because of concealed faults. Faulting is too prevalent to avoid this hazard although the sections were carefully selected and are well exposed. The best indication that they are substantially correct is that the conclusions based on them are suported by variations in thickness and lithology of the basal conglomerate of the Bolsa.

The basal conglomerate of the Bolsa differs in thickness and character from place to place in accordance with the inferred pre-Bolsa geology and topography. Over the upland east of Lime Peak, it is absent locally

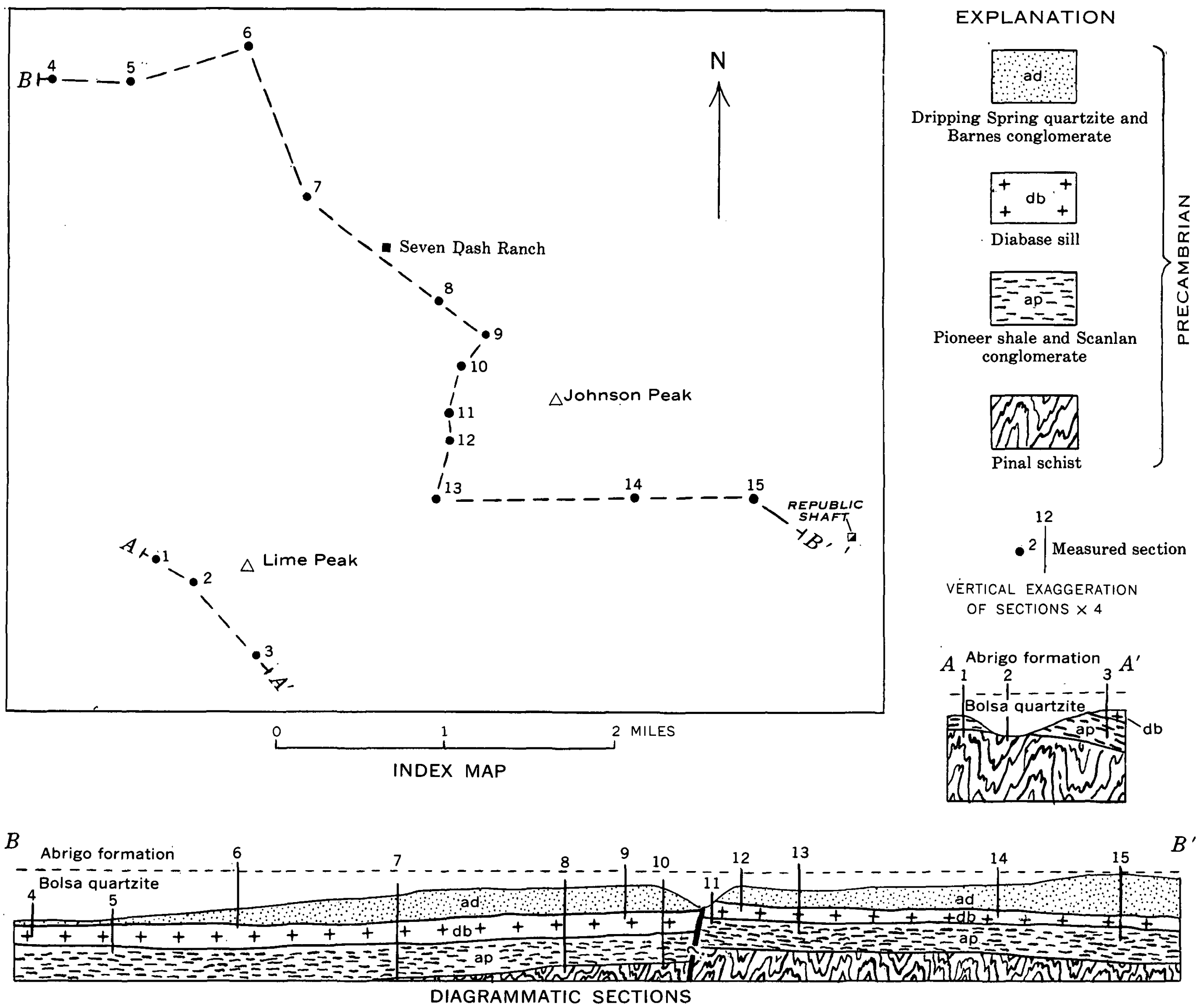

FIGURE 6.—Diagrammatic cross sections showing surface on which the Bolsa quartzite was deposited.

but is generally represented by 1 to 10 feet of conglomerate characterized by angular pebbles and small flat cobbles of the underlying Dripping Spring quartzite in an abundant quartzite matrix. It evidently represents surface rubble only slightly reworked by the advancing Bolsa sea. The angular shape of the fragments proves that the Dripping Spring quartzite was solid rock at the time and precludes much abrasion by wave action. In the pre-Bolsa valleys the conglomerate is as much as 40 feet thick and contains rounded fragments thought to be the partially reworked valley gravels of pre-Bolsa time. At the bottom of the valley west of Johnson Peak, there are angular blocks of Dripping Spring quartzite as much as 6 feet in diameter which may represent landslide material from the steep valley sides (fig. 7).

An unusual facies of the conglomerate is found above the inferred pre-Bolsa hill near Johnson. (See fig. 6, section *B–B′*.) This conglomerate is coarse and contains both angular and rounded boulders. One subangular quartzite block 26 inches in diameter was seen. The conglomerate is 14 feet thick and appears to comprise the entire Bolsa formation. Although an interval corresponding to 106 feet of beds above the conglomerate is covered, the stratigraphic interval between the top of the conglomerate and the top of the lower shale member of the Abrigo is about 100 feet too short to accommodate the normal thickness of the shale alone. This could be due to dynamic thinning by faulting or flowage, but it probably indicates that the hill was not fully buried until Abrigo time.

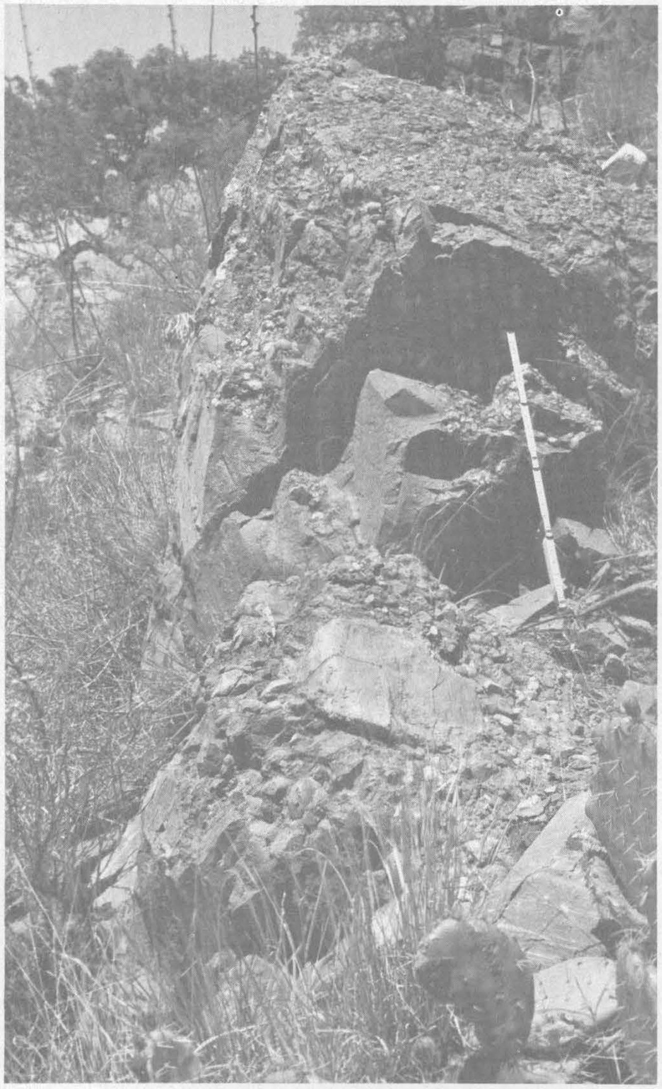

FIGURE 7.—Basal conglomerate of Bolsa quartzite in pre-Bolsa valley west of Johnson Peak. Rule opened to 2 ft. The large angular boulders are of Dripping Spring quartzite. The pre-Bolsa valley here cuts through the Dripping Spring quartzite and the diabase sill, and the conglomerate rests on the Pioneer shale, which is concealed by talus to the left of the outcrop.

Still another facies of the conglomerate is found in the western part of the quadrangle where the Dripping Spring quartzite and Barnes conglomerate are missing. Where a true basal conglomerate is present, as it frequently is, it consists of well-rounded fragments of white, gray, and pink quartzite and quartz, in a quartzite matrix. The composition, size, and roundness of the pebbles strongly suggest that they are reworked pebbles from the Barnes conglomerate.

CAMBRIAN SYSTEM

BOLSA QUARTZITE

The name Bolsa quartzite was proposed by Ransome (1904, p. 28) for the basal quartzite of the Cambrian system at Bisbee. The name was extended by Ransome (1916, p. 148) into the Tombstone district and by Gilluly (1956, p. 14) into the Dragoon mountains immediately south of the Dragoon quadrangle. It is recognized by Stoyanow (1936, p. 466) in the Bisbee-Tucson subarea of southern Arizona. Farther north, quartzite formations which may be equivalent to the Bolsa have been given other names, including the Coronado quartzite (Lindgren, 1905, p. 59) of the Clifton-Morenci district and the Troy quartzite (Ransome, 1916, p. 139) recognized in a large area surrounding Globe and Ray.

The Bolsa quartzite is exposed in all parts of the Dragoon quadrangle where the base of the Paleozoic section is exposed. It is extremely resistant to erosion and characteristically forms conspicuous rocky ridges and cliffs. As abundant slices, the resistant quartzite emphasizes the traces of some of the major thrust faults.

STRATIGRAPHY

Fully developed sections of the Bolsa quartzite show a succession of four transitional units as follows: (1) A basal conglomerate that ranges in thickness and character as described in the preceding section; (2) a lower quartzite unit characterized by beds of dark-brown or red to tan quartzite which, in the western part of the area and in the valley-filling facies farther east, contains granule conglomerate and some pebble conglomerate beds; (3) a higher quartzite unit characterized by white and tan fine- to medium-grained vitreous quartzites; and (4) an upper unit of quartzite or sandstone and interbedded shale. This upper unit represents a gradation into the overlying shales at the base of the Abrigo formation. For mapping purposes the upper contact of the Bolsa was taken arbitrarily as the top of the highest quartzite, 1 foot or more thick. One or more of the units may be missing from a particular section, but the order of succession remains the same.

The quartzite in all the units commonly shows distinctive color banding with light and dark alternating bands both parallel and oblique to the bedding. This color banding, the gritty and pebbly texture, and the lack of feldspar generally serve to identify the Bolsa quartzite where found in fault slices. Casts of worm borings both parallel to and normal to the bedding planes are abundant locally. The lower unit of dark-colored pebbly quartzite is thickest in the thicker sections. Representative sections of the Bolsa quartzite follow.

Section of Bolsa quartzite

[Measured in Johnny Lyon Hills-Kelsey Canyon area (SE¼ sec. 10, T. 15 S., R. 21 E.)]

	Feet
Abrigo formation (in part):	
Shale, olive, fissile, and thin brown sandstone.	
Bolsa quartzite:	
Covered (stream bottom), may conceal fault	10

Section of Bolsa quartzite—Continued

	Feet
Bolsa quartzite—Continued	
Quartzite interbedded with shale; brown quartzite stained black on upper surfaces and in medium-grained vitreous to granular beds 1 to 3 ft thick; yellow-brown to olive-brown fissile somewhat sandy shale in beds generally 2 in. to 1 ft thick, increasing in abundance toward top of unit	34
Quartzite, white to tan with some color banding, fine to medium-grained, vitreous, thick-bedded; some worm boring casts	189
Quartzite, dark-brown to tan; commonly shows alternate light and dark color banding parallel to and across the bedding; medium- to coarse-grained; scattered quartz granules and granule horizons; vitreous, medium to thick-bedded; casts or worm borings	195
Interbedded gritty quartzite and pebble conglomerate; dark chocolate brown at base to medium brown at top; some mottling and color banding of diffusion(?) origin. Medium to thick bedded. Beds of pebble conglomerate, 1 in. to 1 ft thick, occur at 1- to 2-ft intervals throughout unit	52
Total thickness of Bolsa quartzite	480

Unconformity.
Diabase:
Altered green diabase grading upward to dark red-brown hematite-chlorite-clay(?) zone with remnants of ophitic texture.

Section of Bolsa quartzite

[Valley-filling facies quarter of a mile west of Lime Peak (SE¼SE¼ sec. 30, T. 15 S., R. 22 E.)]

	Feet
Abrigo formation (in part):	
Shale.	
Bolsa quartzite:	
Quartzite, white, interbedded with brown sandstone	30
Quartzite, white to light-gray, with red streaks and bands near the base	180
Quartzite, dark-red to reddish-gray; with light colored streaks and bands	85
Conglomerate with rounded boulders of quartzite, quartz, schist, and sandstone as much as 3 ft in diameter	40
Total thickness of Bolsa quartzite	335

Unconformity.
Pinal schist.

Section of the Bolsa quartzite

Upland facies half a mile northwest of Johnson Peak (SE¼NE¼ sec. 21, T. 15 S., R. 22 E.)]

	Feet
Abrigo formation (in part):	
Shale, brown, sandy; a few quartzite beds a ¼ to 2 in. thick.	
Bolsa quartzite:	
Quartzite, gray to pale-brown; interbedded with laminated partly shaly sandstone, beds 1 to 4 ft thick	23
Quartzite, white, vitreous; in part weathering to light-purple or rusty color	84

Section of the Bolsa quartzite—Continued

	Feet
Bolsa quartzite—Continued	
Quartzite, deep-purple, vitreous; with white quartzite lenses, 1 to 2 in. thick, parallel to the bedding planes	5
Quartzite, white, vitreous; with thin laminations of deep-purple quartzite near top, and scarce small angular fragments of Dripping Spring quartzite near base, which is on irregular surface of erosion	4
Total thickness of Bolsa quartzite	116

Unconformity.
Dripping Spring quartzite:
Arkosic quartzite, banded pink.

THICKNESS

The thickness of the Bolsa quartzite in the Johnny Lyon Hills-Kelsey Canyon area ranges from 390 to 480 feet where measured. In the Little Dragoon Mountains, it was found to range from 335 feet where it fills the pre-Bolsa valley near Lime Peak to possibly as little as 14 feet near Johnson; the average is near 120 feet. The thicknesses in the western part of the area are about the same as those reported south of the quadrangle. Ransome measured 430 feet at the type section at Bisbee (1904, p. 29) and 440 feet at Tombstone (1916, pl. 25). Gilluly (1956, p. 15) measured 302 feet in the Dragoon Mountains 4.3 miles northwest of South Pass. His later mapping suggests that this section may be in error due to faulting and indicates that farther north in the vicinity of Cochise Stronghold, the thickness must be virtually as great as it is to the south. The thinning of the formation in the Little Dragoon Mountains seems to be due largely to its overlap onto pre-Bolsa hills in that area.

AGE AND CORRELATION

There is no direct fossil evidence for the age of the Bolsa quartzite in the Dragoon quadrangle. The same is true at the type locality where Ransome (1904, p. 30) placed the formation in the Middle Cambrian because of its gradational relation to the overlying Abrigo limestone which could be dated. Correlation of the Dragoon quadrangle section with the type Bolsa is based on strong similarities in lithology and identical relations to the overlying Abrigo which contains fossils of Middle Cambrian age in its lower part.

The Bolsa quartzite is probably equivalent to much or all of the Troy quartzite of its type area in the Dripping Spring Mountains (Ransome, 1916, p. 139). Cambrian fossils have been found in the Troy at about half a dozen localities in this general area (Stoyanow, 1936, p. 475). The dark-colored quartzite in the lower part of the Bolsa in the Dragoon quadrangle is similar in many ways to the typical Troy. In the Johnny

Lyon Hills-Kelsey Canyon area, the lower beds of the Bolsa are crossbedded and notably pebbly like the lower massive beds of the Troy at its type locality (Ransome, 1916, p. 139). The weathered surfaces commonly show diffusion rings and bands which are very similar to those figured by Ransome (1919, pl. 14–A) from the Ray area. The presence of worm borings is like the typical Troy (Ransome, 1916, p. 139–140). The Troy, like the Bolsa, has an unconformity at its base. In the eastern part of the Mescal Mountains and in the Hayes Mountains southeast of Globe, Darton found Troy lying unconformably on diabase, as does the Bolsa in the Dragoon quadrangle. Recently M. H. Krieger found the same Troy-diabase relation in the Holy Joe Peak quadrangle southeast of Winkelman (A. F. Shride, written communication, Jan. 8, 1958).

According to Lochman-Balk (1956, p. 539), the Troy, as it has been mapped north of Winkelman, is predominantly Precambrian but includes a discontinuous overlapping wedge of Cambrian age. She restricts the name Troy to the Precambrian part and thinks the Cambrian part should be called Bolsa. This interpretation would reconcile presently conflicting geologic relations of the diabase, which, north and west of the Mescal Mountains, generally intrudes the Troy. The thick Troy section in the Sierra Ancha Mountains is wholly lacking in worm borings and is intruded by diabase throughout (A. F. Shride, written communication, Jan. 1, 1958).

The relation of the Bolsa quartzite to the Coronado quartzite of the Clifton-Morenci district is unknown. The Coronado was originally assigned to the Cambrian by Lindgren (1905, p. 61) on the basis of stratigraphic relations and the presence of poorly preserved fossils identified by Walcott as *Lingulella,* similar to a Cambrian form. Darton (1925, p. 45) suggested a general correlation with the Bolsa. However, the Coronado is overlain by fossiliferous limestone of Ordovician age, and Stoyanow (1936, p. 478) has questioned the paleontological grounds for assigning it to the Cambrian. He (Stoyanow, 1942, p. 1265) thinks it is probably Ordovician.

ABRIGO FORMATION

The name Abrigo limestone was proposed by Ransome (1904, p. 30) for the Cambrian limestone overlying the Bolsa quartzite in the Bisbee area. The name was extended by Ransome (1916, p. 148) into the Tombstone district and by Gilluly (1956, p. 16) to the southern border of the Dragoon quadrangle. The formation was recognized by Darton (1925, p. 47) in many parts of southern Arizona.

Stoyanow (1936, p. 465) has suggested that the name Abrigo limestone be changed to Abrigo formation and that it be restricted to that part of the classic Abrigo which contains the Upper Cambrian *Crepicephalus-Arapahoia* fauna. He has proposed new formational names for the rest of the type Abrigo. His classification and terminology have not been adopted by the Geological Survey. Although Abrigo formation is here used in place of Abrigo limestone because the Abrigo in the Dragoon quadrangle is less than half limestone, the name is used in the original sense of Ransome, not in the restricted sense of Stoyanow.

The Abrigo formation is exposed in all the areas of older rocks in the Dragoon quadrangle except the ranges in the northeastern corner of the quadrangle. Complete sections are found at many places in the Johnny Lyon Hills-Kelsey Canyon area and in the Little Dragoon Mountains. The section exposed at the north end of the Dragoon Mountains is thin because it is involved in the thrust faulting that affected that area. At the western base of the Gunnison Hills only the upper part is exposed, because of overlapping alluvium. The formation is not exposed in the Steele Hills or at the south end of the Winchester Mountains though it appears in the Winchester Mountains about a mile north of the quadrangle boundary.

STRATIGRAPHY

Representative stratigraphic sections of the Abrigo formation in the Dragoon quadrangle are presented in plate 3. As shown in these sections, there are three members, with essential features as follows:

Lower member: shale, mostly olive, fissile; with subordinate beds of thin sandstone and dolomite in lower part, thin gray limestone beds common in upper part, and with a capping tongue of crossbedded quartzite in the northwestern part of the quadrangle. Total thickness 300 to perhaps as much as 500 ft.

Middle member: thin-bedded limestone with abundant, mostly irregular partings of silt and sand, some limy sandstone beds, numerous intraformational conglomerates. Total thickness 175 to 255 ft.

Upper member: sandy dolomite, dolomitic sandstone, and scarce quartzite beds; commonly has quartzite bed at top. Dolomite grades to limestone in northwestern corner of the quadrangle. Total thickness 85 to 155 ft.

No evidence of unconformity between the members was noted but they are sharply defined and are shown separately on the large-scale map of the Johnson Camp mining district (pl. 6).

The gradational lower boundary of the formation was discussed in connection with the Bolsa quartzite. The upper boundary, between the quartzite, laminated sandy dolomite, or limestone of the Abrigo formation and the relatively pure and more massive dolomite at the base of the Martin formation, is generally clear cut. Small outcrops of the Abrigo are generally easy to distinguish from the other formations by their distinctive thin bedding, abundant beds of intraformational conglomerate, and by peculiar irregular partings and anastomosing seams of silt in many of the limestone beds. Small outcrops of the sandy dolomite beds of the upper member may be very difficult to distinguish from similar beds in the middle part of the Martin formation.

Several lateral facies changes in the Abrigo formation are of interest. In the vicinity of Kelsey Canyon, about 50 feet of crossbedded ledge-forming quartzite occurs at the top of the lower member. This quartzite unit thins progressively toward the south and in the Johnny Lyon Hills is represented by as little as 2 feet of flaggy quartzite and calcareous sandstone. The unit is not distinguishable in the Little Dragoon Mountains though a single 6-inch quartzite bed at its horizon was noted at one place. The thickness and lithology of the unit remain the same when the major thrust faults of the Johnny Lyon Hills are crossed, suggesting that the direction of fault movement may have been nearly normal to the direction of facies change.

The upper member in the northwestern corner of the quadrangle is unusual in several respects. A quartzite unit commonly found at the very top of the member is not seen north of the Willcox-Cascabel road. In this area, about 50 feet of fossiliferous limestone overlies the sandy dolomite. The limestone is characteristically pinkish gray to pink, coarsely crystalline, glauconitic, and thin to medium bedded. South of the road these limestone beds become mottled with yellow dolomite spots and zones which both parallel and crosscut the bedding and appear in all of the beds. Less than 2 miles south of the road, this part of the section is entirely dolomite. The evidence suggests lateral gradation. Nowhere in the southern Johnny Lyon Hills or other parts of the Dragoon quadrangle has any limestone been observed in the upper member.

An atypical limestone bed, mapped with the Abrigo formation, appears sporadically at the top of the upper member in the area north of the Willcox-Cascabel road. It has a maximum thickness of 10 feet, is blue gray, massive, and finely crystalline. It rests on thin-bedded pink limestone and locally contains, in its lower part, a very coarse intraformational conglomerate made up of fragments of the pink limestone which is only slightly dislocated from the underlying beds. This gray limestone is overlain by typical basal dolomite of the Martin. No fossils have been found and the age and relation of this bed to the disconformity at the base of the Martin are not known.

Many beds in the Abrigo within the area of this report contain unusually large amounts of potassium feldspar. Some plagioclase is also present but is less abundant than orthoclase. The amount of feldspar is not uniform either in percentage of the rock or in comparison to the amount of quartz. Calcareous sandstone commonly contains 20 to 40 percent feldspar by volume and has a feldspar to quartz ratio near 1:1. The feldspar to quartz ratio is more variable in the silty limestone but probably averages about 1:1. It is commonly higher in the calcareous shale. The dolomitic rocks generally contain lower proportions of feldspar than the calcareous rocks, though one dolomitic sandstone specimen studied had about 40 percent feldspar and a feldspar to quartz ratio near 1:1. The ratio is more commonly between 1:2 and 1:4, and some sandy dolomite beds contain almost no feldspar. The quartzite beds contain very little feldspar.

The abundance of feldspar in the Abrigo was not suspected until microscopic study of the metamorphic facies near Johnson revealed that orthoclase was an abundant constituent. This encouraged similar study of the unmetamorphosed rocks for comparison. Powders, insoluble residues, and a few thin sections from all parts of the area were studied under the microscope, and the conclusion reached was that a generally high content of feldspar is a widespread characteristic of the formation and is not related to metamorphism or evident "mineralization" of any kind. To determine, if possible, whether this characteristic is general or local in nature, seven samples from the Bisbee area, kindly furnished by Dr. E. D. Wilson of the Arizona Bureau of Mines, were also studied. Some of these samples were high and some low in feldspar. In the Huachuca Mountains, the formation appears to be low in feldspar judging from preliminary studies by Mr. Robert Weber (oral communication, 1950) and from our examination of a few samples kindly furnished by Mr. Weber. Thus no general conclusions of a regional nature are yet possible.

The origin of the feldspar is not known, but the available evidence indicates that most of it is not detrital, at least in the ordinary sense. Rounded detrital grains of feldspar do occur but do not make up more than 1 or 2 percent of any of the specimens studied. Where present in large amounts, the feldspar is recrystallized. Good crystal outlines are rare but have been seen in some specimens. Derivation from some fine-grained constituent of the original sediment seems indicated by the negligible amount of feldspar in the quartzite beds, which represent layers of "clean" sand, and in the cross-laminated dolomite beds, like the one shown in figure 8, which evidently were deposited as coarse carbonate sands. The crossbedding in such rocks indicates deposition in water of sufficient turbulence to have washed away the finer sediment. It is thought that the abundant feldspar found in other beds is related to authigenic recrystallization of the fine sediment, which may have been potassium-rich clay. The feld-

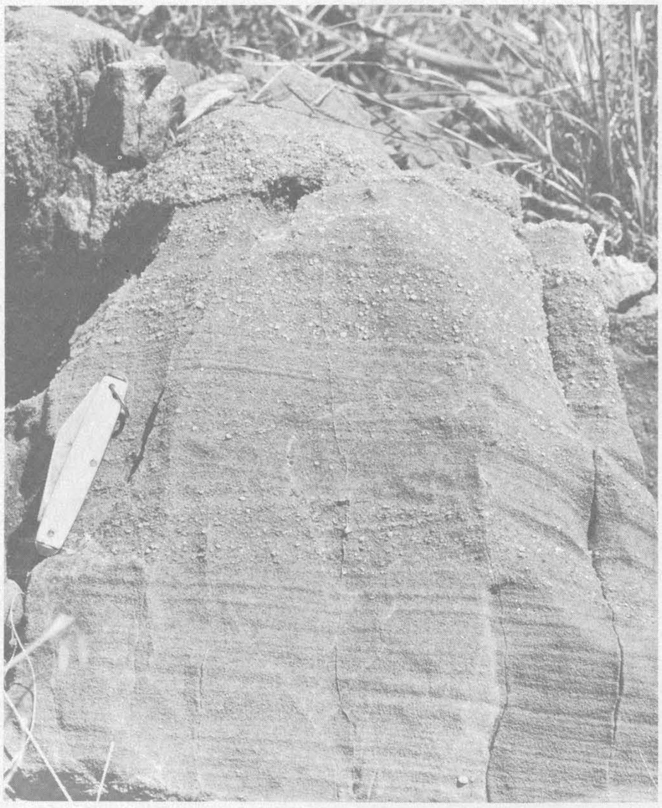

FIGURE 8.—Sugary cross-laminated dolomite with granules of quartz near top of Abrigo formation, 3,500 feet west of Moore shaft.

spar probably should be classed with the "authigenic feldspar" occurrences in limestone. Authigenic albite has been described by Singewald and Milton (1929) in limestone of Ordovician age in New York, and large quantities of authigenic orthoclase have been described by Daly (1917) in a dolomite of the Belt series in British Columbia. Daly thought that the feldspar formed before the sediment was consolidated or deeply buried and at a relatively low temperature, perhaps below 70° C.

The Abrigo formation contains most of the copper-zinc ore in the Johnson Camp district, and therefore the lithologic character in that area is of particular interest. A total of 10 readily recognizable divisions of the formation have been designated by number for convenience in reference. Most of these units have at least one gradational contact, and their exact definition is therefore arbitrary. The divisions are intended for purely local use near Johnson without implication as to their regional extent. It is of interest to note that several are recognizable in all parts of the Dragoon quadrangle and apparently over a considerably wider area, judging from our regional reconnaissance and from published sections. The principal characteristics of the units are given on plate 3. (See particularly sections 3 and 4). Some additional details follow.

NOTES ON ABRIGO SECTION IN LITTLE DRAGOON MOUNTAINS AND VICINITY OF JOHNSON

Lower member is about 300 ft thick (same as unit 1).

Unit 1.—The lower part of unit 1 is brown sandy and not very fissile shale. The upper part is fissile olive-drab shale. The lower part contains numerous quartzite beds less than 2 in. thick and a few tan-weathering dolomite beds as much as 3 or 4 ft thick. Dolomite interbeds are confined to the lower 100 ft; above this, gray limestone interbeds appear and become increasingly abundant toward the top. The limestone resembles the overlying unit and occurs in zones from a few inches to as much as 20 ft thick. Beds of intraformational flat-pebble conglomerate are common in the limestone. Thin beds of pisolitic limestone were observed at several places about 185 ft above the base. The member as a whole is easily eroded and commonly not well exposed. The shale is converted by metamorphism to shaly biotite hornfels and the limestone to garnet- or epidote-rich rocks. Where metamorphism has been extreme, considerable epidote and garnet have formed in the shale.

Middle member consists of 225 to 255 ft of calcareous rocks (units 2 through 5).

Unit 2 (thin-bedded limestone 70 to 120 ft thick).—Unit 2 is fine- to medium-grained gray limestone in beds which are generally 2 or 3 in. and rarely more than 6 in. thick and separated by numerous irregular partings of silt about a quarter of an inch thick. Some beds contain brachiopod and trilobite fragments. The base of the unit is sharp; the upper contact is gradational. The unit is one of the last to be notably altered by contact metamorphism, but it has been converted to garnetite at some places near Johnson and to nearly white diopside-rich rock in parts of the Republic mine. Except where garnetized, the member is easily eroded and commonly forms a uniform slope with unit 1.

Unit 3 (thin-bedded limestone, 30 to 70 ft thick).—Unit 3 is similar to unit 2 except that it has more abundant and somewhat thicker silty partings that weather rusty black. They are resistant to erosion, weather in relief, and cause the unit to form relatively bold outcrops. If the slopes underlain by the Abrigo are viewed from a distance, a nearly black band formed by units 3 to 5 is generally conspicuous. Units 2 and 3, which are arbitrary divisions of a transitional series, are called "the crenulated limestone" by engineers of the Coronado Copper and Zinc Co., because of the irregular silty partings. These units look exactly like the typical exposures of cherty Abrigo photographed by Ransome (1916, pl. 30) in the Tombstone and Bisbee districts, but the partings are silt not chert in the Dragoon quadrangle.

Unit 4 (calcareous sandstone, 23 to 53 ft thick).—Unit 4 consists of fine-grained calcareous sandstone, which weathers reddish brown. The beds are 3 to 6 in. thick and are crossbedded locally. Thin interbeds of gray limestone are commonly present, especially near the top and bottom where the sandstone grades by interbedding into the adjacent units. In areas of metamorphism, the unit is readily altered to garnetite, as is the overlying limestone unit.

Unit 5 ("trilobite coquina," 33 to 55 ft thick).—Unit 5 consists of coarsely crystalline reddish-gray limestone that contains abundant trilobite fragments and is interbedded with much flat-pebble conglomerate and thin rusty layers of sandstone and shale. The beds are generally less than 12 in. thick. The base of the unit is gradational but the top is sharp. In a wide aureole around the Texas Canyon quartz monzonite stock, the shale beds have been converted to biotite hornfels; the limestone beds are much less widely converted to granular garnetite. Where metamorphism was intense, the hornfels was destroyed and the unit is represented by unbanded garnetite. Unit 5 was very favorable for metalization and contains most of the ore in the Republic, Mammoth, Copper Chief, and Moore mines as well as the showings at numerous prospects (pl. 6). Additional details of composition and lithology of the unit are presented in an earlier publication (Cooper, 1957).

Upper member consists of 95 to 155 feet of dolomitic rocks (units 6 through 10)

Unit 6 (interbedded dolomitic sandstone and sandy dolomite, 23 to 39 ft thick).—Unit 6 consists of medium- to coarse-grained dolomitic sandstone and sandy dolomite in beds 6 to 12 in. thick. Crossbedding is evident locally, and there are partings of green shale between some of the beds. Like most of the upper member of the Abrigo, the unit was readily altered by metamorphism to granular silicate rock that is nearly white on fresh fracture and thus distinguishable from the brown to green rocks derived from the underlying calcareous rather than dolomitic beds. The difference in appearance is due to difference in composition. The underlying limestone units contain the lime silicates garnet and epidote, whereas these colored minerals are generally lacking from the upper sandy dolomite beds which are characterized by nearly colorless magnesian silicates such as diopside and tremolite. The granular "white tactite" derived from unit 6 generally contains, particularly in its lower part, thin porcelaneous bands, presumably derived from the shale partings. (See fig. 9.) Chemical analyses of the unit and additional details of lithology are presented in an earlier publication (Cooper, 1957).

Unit 7 (quartzite, 2 to 7 ft thick).—Unit 7 consists of medium- to fine-grained generally white quartzite locally interbedded with brown sandstone. The quartzite is vitreous, resistant, and commonly well exposed. The bed is only rarely distinguishable near Johnson.

Unit 8 (sandy dolomite, 37 to 51 ft thick).—Unit 8 is gray to brown sandy dolomite much like unit 6. The two are indistinguishable in their metamorphosed condition.

Unit 9 (laminated dolomitic sandstone, 26 to 46 ft thick).—Unit 9 is fine-grained dolomitic sandstone, which is generally laminated and very commonly contains scattered grains and lenses of coarse frosted sand near the top. The surface weathers to a buff or rusty color and a ridged or grooved surface. On metamorphism, most of the unit is converted to white tactite like units 6 and 8. In the vicinity of Johnson, There is a sandy dolomite bed about 10 ft thick near the top of the unit. This bed, shown in figure 8, is represented in the mining area by marble with scattered spots of forsterite, or more commonly its alteration product green serpentine (fig. 10). In its metamorphosed condition the bed is known as the lower serpentine marker.

Unit 10 (quartzite as much as 20 ft thick).—Unit 10 is pure white quartzite, which at many places grades downward into the dolomitic sandstone below. It generally ranges from 1 to 20 ft in thickness and is remarkably persistent though it is locally absent for short distances. The bed is nonfossiliferous and thus could be assigned to the overlying Martin formation. It was assigned to the Abrigo rather than the Martin because of its gradational lower contact. A very similar quartzite bed probably the same bed, occurs at Bisbee and at Tombstone and was similarly interpreted by Ransome (1916, p. 145, 148) for the same reason. Near Johnson, unit 10 is present and only slightly altered near the O.K. mine but contains much diopside and is generally obscure near the Republic, Copper Chief, and Mammoth mines where metamorphism was more intense.

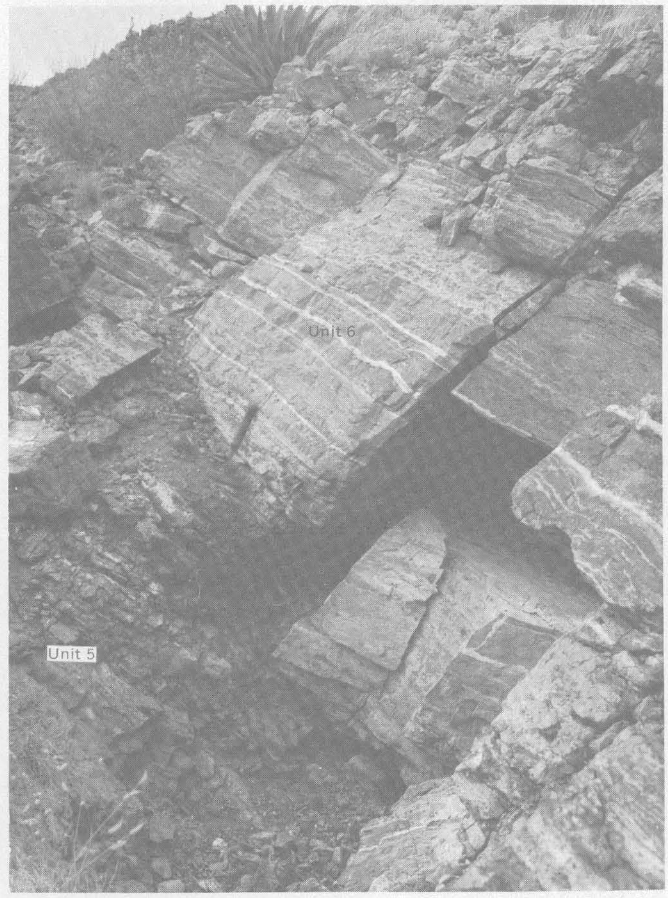

FIGURE 9. White tactite (unit 6) on garnetite (unit 5) of Abrigo formation near Johnson. Joint blocks of white tactite have caved into stope in garnetite. Point of pick marks contact of units. The white tactite is a uniform and structurally competent unit throughout the Johnson district.

Thickness.—Unfaulted and unmetamorphosed sections of the Abrigo formation in the Dragoon quadrangle range in thickness from about 700 feet in the Little Dragoon Mountains to about 800 feet in the northwestern part of the quadrangle. Measurements reported from nearby areas are as follows:

	Feet	
Type section near Bisbee	770	(Ransome, 1904, p. 31.)
Tombstone Hills	844	(Gilluly, 1956, p. 17.)
Southern Dragoon Mountains	835½	(Gilluly, 1956, p. 16–17.)
Whetstone Mountains	749	(Gilluly, 1956, p. 17.)
Santa Catalina Mountains (used the name Abrigo as in this report).	750	(Stoyanow, 1936, p. 477.)

Postdepositional processes of several kinds have modified the thickness in the Dragoon quadrangle. Being relatively weak structurally, the formation has been thickened or thinned locally by deformational movements. Dynamic thinning is common in zones of thrust

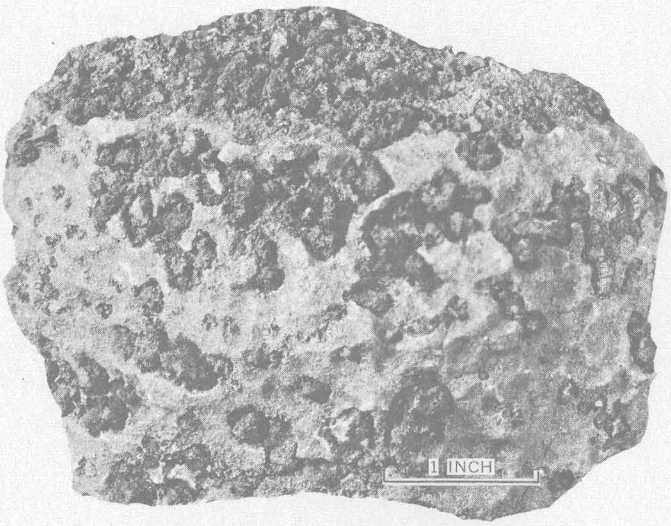

FIGURE 10.—Metamorphosed equivalent of the bed shown in figure 8. Near Moore shaft. Each original quartz granule is represented by an aggregate of forsterite surrounded by a narrow rim of calcite that has weathered to form a depression. Matrix is dolomite except in upper part of specimen where no dolomite remains. The forsterite is generally serpentinized, and the bed is known as the lower serpentine marker.

faulting. In the metamorphosed facies near Johnson, the middle and upper members are thinner than in nearby unmetamorphosed sections. There is no indication that this is due to deformational movements, and it is probably due to shrinkage related to the metamorphism as discussed in detail in an earlier report (Cooper, 1957).

FAUNA AND AGE

By A. R. PALMER

The faunas of the Abrigo formation in the Dragoon quadrangle range in age from late Middle Cambrian through the early two-thirds of the Late Cambrian. Representatives of possibly two late Middle Cambrian zones and the *Cedaria*, *Crepicephalus*, and *Aphelaspis* zones of Dresbach age (early Late Cambrian) and the *Elvinia* and *Ptychaspis* zones of Franconia age (middle Late Cambrian) are present.

The faunas are characteristic of, but not necessarily restricted to, some of the recognized units of the Abrigo formation, as follows: Unit 5 (upper part) *Aphelaspis* zone, (lower part) *Crepicephalus* zone; units 2 and 3 of *Cedaria* zone; unit 1 of Middle Cambrian.

North of 32°10′ latitude, red granular limestone containing the *Elvinia* and *Ptychaspis* faunas is present in the interval between unit 5 and the Martin limestone. South of that latitude, the equivalent horizons are within the nonfossiliferous brown dolomite and quartzitic beds of units 6 to 10.

Most of the genera and many of the species of the Abrigo faunas are known at numerous localities in the Western United States. The fauna of Dresbach age is most similar to that discussed by Lochman and Duncan (1944) from the Pilgrim formation in central Montana.

Faunal lists of individual collections are given below. Numbers in parentheses refer to assigned numbers in the Geological Survey collections.[5] Only generic identifications are given, specific identifications are withheld until a detailed study of the faunas can be undertaken.

Little Dragoon section

[Sec. 21, T. 15 S., R. 22 E.[6]]

Upper Cambrian
- Dresbacharge:
  - *Aphelaspis* zone (739)—unit 5
    - *Aphelaspis* sp.
    - *Glaphryaspis* sp.
    - *Dictyonina* sp.
  - *Crepicephalus* zone (738)—unit 5
    - *Crepicephalus* sp.
    - *Llanoaspis* sp.
    - *Coosina* sp.
    - *Tricrepicephalus* sp.
  - *Cedaria* zone (737)—unit 2
    - *Arapahoia* sp.
    - *Cedaria* sp.
    - *Cedarina* sp.
    - *Kormagnostus* sp.
    - *Meteoraspis* sp.
    - *Paracedaria* sp.
    - *Semnocephalus* sp.
    - *Syspacheilus* sp.

Middle Cambrian (735)—unit 1
- *Ehmania* sp.

Johnny Lyon Hills section

[Sec. 11, T. 15 S., R. 21 E.]

Upper Cambrian
- Dresbacharge:
  - *Aphelaspis* zone (1232)—unit 5
    - *Aphelaspis* sp.
  - *Crepicephalus* zone (1231)—unit 5
    - *Crepicephalus* sp.
    - *Llanoaspis* sp.
    - *Coosina* sp.
    - *Tricrepicephalus* sp.
  - *Cedaria* zone (1230)—unit 3
    - *Coosia* sp.
    - *Genevievella* sp.
    - *Tricrepicephalus* sp.
  - *Cedaria* zone (1229)—unit 2
    - *Arapahoia* sp.
    - *Cedaria* sp.
    - *Kormagnostus* sp.
    - *Densonella* sp.
    - *Semnocephalus* sp.
  - *Cedaria* zone (1228)—unit 2
    - *Cedaria* sp.
    - *Kormagnostus* sp.
    - *Meteoraspis* sp.
    - *Semnocephalus* sp.

Middle Cambrian (1227)—unit 1
- *Ehmania* sp.

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[5] These numbers are also used to indicate relative stratigraphic positions of collections on plate 3.

[6] Collections made in 1938 by Bridge and Gilluly, whose section is given in detail by Gilluly (1956, p. 18–19).

Miscellaneous collections

Upper Cambrian:

Ptychaspis zone (1233)—NE¼ sec. 27, T. 14 S., R. 21 E., about 10 ft below Martin
- *Idahoia* sp.
- *Drumaspis* sp.

Elvinia zone (1247)—NE¼ sec. 21, T. 14 S., R. 21 E., about 10 ft below Martin
- *Camaraspis* sp.
- *Dellea* sp.
- *Elvinia* sp.
- *Irvingella* sp.
- *Kinbladia* sp.
- *Linnarssonella* sp.
- *Pseudagnostus* sp.

Crepicephalus zone (1246)—SE¼ sec. 16, T. 15 S., R. 22 E., unit 5
- *Crepicephalus* sp.
- *Llanoaspis* sp.
- *Coosina* sp.
- *Tricrepicephalus* sp.

Cedaria zone (1243)—SE¼ sec. 20, T. 15 S., R. 21 E., unit 2, 49 ft above Southern Belle quartzite of Stoyanow (1936, p. 476), at top of unit 1
- *Cedaria* sp.
- *Coosella*? sp.
- *Kormagnostus* sp.

Cedaria zone (1242)—SE¼ sec. 20, T. 15 S., R. 21 E., unit 2, 17½ ft above Southern Belle quartzite
- *Kormagnostus* sp.
- *Semnocephalus* sp.

Cedaria zone (1245)—SE¼ sec. 16, T. 15 S., R. 22 E., unit 2, 430 ft below Martin-Abrigo contact
- *Arapahoia* sp.
- *Coosella* sp.
- *Dicellomus* sp.
- *Kingstonia* sp.
- *Meteoraspis* sp.

Middle Cambrian (1244)—NE¼ sec. 21, T. 15 S., R. 22 E., unit 1, 150 ft above Bolsa-Abrigo contact
- *Alokistocare* sp.
- *Elrathia*? sp.
- *Nisusia*? sp.
- *Olenoides* sp.

Supplemental note by J. R. Cooper.—Prior to Mr. Palmer's studies of our collections the following fossil was identified by Dr. G. A. Cooper of the U.S. National Museum.

Upper Cambrian—SE¼SW¼ sec. 4, T. 16 S., R. 23 E., unit 8
- *Billingsella* sp.

CORRELATION AND REGIONAL RELATIONS

Stoyanow (1936, p. 482) showed that the Abrigo limestone as defined by Ransome at Bisbee is represented by shale, sandstone, and quartzite at the north end of the Santa Catalina Mountains. Out work in the Dragoon quadrangle, which lies between these two localities, supports the conclusion of a gradual northward change in facies and clarifies the relations between several of the formations into which Stoyanow divided these rocks.

It is clear that the quartzite at the top of the lower member in the Kelsey Canyon-Johnny Lyon Hills area is the Southern Belle quartzite of Stoyanow (1936, p. 476), of the Santa Catalina Mountains, and that this is the southern margin of that unit. The shale and limestone that underlie this quartzite and interfinger with it where it pinches out have great lithologic and faunal similarity to the Cochise formation of Stoyanow (1936, p. 466) of the Whetstone Mountains. Therefore, the correlation (Stoyanow, 1936, p. 482) of the Cochise formation with the Southern Belle quartzite and the Santa Catalina formation of Stoyanow (1936 p. 476)—which underlies the Southern Belle in the Santa Catalina Mountains—is substantiated. Although the Santa Catalina and Cochise formations represent somewhat different facies, both are charaterized by abundant clastic material and the justification for two different formational names may be questioned. For the purposes of geologic mapping it would be preferable to have a single name applied to the clastic-rich facies without regard to faunal zones. Such a unit is readily recognizable in the Dragoon quadrangle (lower member), where it contains fossils of Middle Cambrian age. It is also recognizable as the bottom 222½ feet of the section measured by Gilluly (1956, p. 17–18) in the Dragoon Mountains to the south. In the Tombstone Hills (Gilluly, 1956, p. 17), the basal clastic-rich zone is very much thinner and fossils of Middle Cambrian age are found high in the overlying limestone facies. No basal clastic-rich zone has been reported in the Bisbee district.

The pink limestone at the top of the Abrigo formation in the northwestern part of the Dragoon quadrangle is very similar in lithology to the Rincon limestone of Stoyanow, of the Whetstone Mountains (1936, p. 471) and contains a fauna of similar age. The transition of this pink limestone to dolomite has already been described. This dolomite in the southern part of the quardangle has a quartzite parting bed at the top. In this and in the faunal assemblage it is similar to the Copper Queen limestone of Stoyanow (1936, p. 469–470) of the Bisbee area.

The broader regional relations of Cambrian sections in Arizona have been discussed by Stoyanow (1936, p. 462–481; 1942, p. 1261–1265), Gilluly (1956, p. 24–25), and Lochman-Balk (1956, p. 538–561). Stoyanow (1942, p. 1263) postulated a persistent land barrier called Mazatzal Land across central Arizona separating a southeastern basin of deposition from another basin in the northwestern part of the State. Lochman-Balk (1956, p. 552) believed the two basins represent embayments from the same seaway to the west, separated by a peninsula, the Defiance positive element, that extended westward from New Mexico but was largely submerged by the middle of Late Cambrian time.

CAMBRIAN-DEVONIAN HIATUS

In the Dragoon quadrangle, the Abrigo formation is overlain with apparent conformity by the Martin formation of Late Devonian age. The same is true over several thousand square miles to the south where the Abrigo is generally capped by a thin quartzite bed. Gilluly (1956, p. 25) discussed this relation in detail. He concluded that the quartzite bed represents a regressive sandstone marking the withdrawal of the Abrigo sea and that the area remained virtually at sea level, undergoing neither erosion nor deposition, during all of Ordovician, Silurian, and part of Devonian time. If this is correct—and we have no alternative hypothesis—the beds of Ordovician age identified in the Clifton-Morenci district (Lindgren, 1905, p. 65–66) and at Dos Cabezos (Gilbert, 1875, p. 511–513) never extended over the area. Farther north in Arizona, in the Mescal and Hayes Mountains about 70 miles northwest of the Dragoon quadrangle, there is a conspicuous unconformity at the base of the Martin as long ago noted by Darton (1925, p. 255–257).

DEVONIAN SYSTEM

MARTIN FORMATION

The name Martin limestone was proposed by Ransome (1904, p. 33) for the limestone of Devonian age of Mount Martin, near Bisbee. He later (Ransome, 1916, pl. 25) extended the name into the Tombstone, Globe, Ray, and Roosevelt areas. We use the name Martin formation in this report, rather than Martin limestone, because the formation is composed of dolomite and terrigenous clastic rocks in the Dragoon quadrangle.

The Martin formation is exposed at many places in the Little Dragoon Mountains and in the Johnny Lyon Hills-Kelsey Canyon area; it crops out also at several places on the west side of the Gunnison Hills and as a narrow fault slice at the north end of the Dragoon Mountains. In all these areas it is a relatively weak formation and, with the Abrigo, commonly forms subdued topography between ridges or cliffs formed by the Bolsa quartzite and the Escabrosa limestone. The top unit of the Martin as here defined is a particularly weak shale bed 20 to 35 feet thick, which forms grassy swales and saddles. In the vicinity of Johnson the shale has been metamorphosed to hard hornfels and forms a low ridge. A gray dolomite unit near the top of the formation makes good outcrops and even cliffs at some places.

STRATIGRAPHY

The Martin formation near Bisbee is dominantly limestone with some pink shale in the lower half (Ransome, 1904, p. 34–35). It grades into an arenaceous facies in central Arizona (Stoyanow, 1936, p. 492–494). In the Dragoon quadrangle, it is about half shale, sandstone, and sandy dolomite and half relatively pure dolomite. The presence of dolomite is unlike the Bisbee section which is typically nonmagnesian (Ransome, 1904, p. 35) but is like the Ray-Globe section which is generally magnesian (Ransome, 1916, p. 141). In the Little Dragoon Mountains the carbonate units of the Martin are entirely dolomite, judging by field tests with dilute acid. Scarce beds and lenses of limestone are associated with the dolomite in the Gunnison Hills and for several miles south of Kelsey Canyon.

The Martin has certain distinctive lithologic characteristics. The beds are generally 1 to 3 feet thick and thus are intermediate between the thinner beds of the Abrigo and the thicker beds of the Escabrosa. Some of the dolomite units are relatively pure and characteristically weather gray, unlike the brown-weathering dolomite beds in the Abrigo. Their fine to medium grain thinner bedding and intercalation between sandy or shaly units distinguish them from most of the Escabrosa. The basal unit of the Escabrosa, however, is fine-grained dolomite somewhat resembling the Martin lithologically. Fortunately the persistent shale unit at the top of the Martin provides an easily identified plane of separation at most places. The shale in the Martin is generally pink whereas that in the Abrigo is green. The sandy dolomite, sandstone, and quartzite beds are hard to distinguish from some beds in the upper member of the Abrigo.

Typical sections of the Martin formation in the Dragoon quadrangle are given on plate 4. Throughout the quadrangle, the following four parts are recognizable:

	Units distinguished in sections 2 and 3
Shale	7
Dolomite	6
Diversified clastic-rich zone, variable in detail	2–5
Dolomite	1

No basal sandstone or conglomerate is present, but in other respects the general sequence resembles the Martin section near Globe, 85 miles to the north (Huddle and Dobrovolny, 1952, p. 108–109; Peterson, 1954).

The Martin section in the Johnson district and in the Little Dragoons is divided into two members and seven numbered units to assist in working out structure. These divisions are shown in sections 2 and 3 (pl. 4) and are described in detail in the following paragraphs.

NOTES ON MARTIN SECTION IN LITTLE DRAGOON MOUNTAINS AND VICINITY OF JOHNSON

Lower member (consisting of units 1 through 3).

Unit 1 ("elephant-hide" dolomite, 25 to 45 ft thick).—Unit 1 is a fine-grained commonly porcelaneous dolomite which weathers to an irregular ridged surface resembling elephant's hide. The rock is gray except for the lowermost 2 to 15 feet which, in an unmetamorphosed condition, is tan and aphanitic. Scattered grains of quartz and small calcite geodes are present at some places. The unit is generally little altered by metamorphism except for recrystallization and local dedolomitization. Copper showings occur in places, and the unit yielded a little ore from open pits on the St. George claim and along the Old Manto fault 300 ft northeast of the Mammoth shaft.

Unit 2 (dolomitic shale and siltstone, as much as 20 ft thick).—Unit 2, which can be distinguished locally, consists of dolomitic shale and siltstone that weathers reddish brown. Where unmetamorphosed it is easily eroded and commonly concealed, but where metamorphosed it is a hard light-gray hornfels which generally crops out well and yields much rubble. The member is closely allied with unit 3 for where unit 2 thins and disappears unit 3 generally thickens correspondingly.

Unit 2 (reddish-brown sandstone and quartzite, 15 to 40 ft thick).—Unit 3 is fine- to medium-grained sandstone or quartzite, which weathers brown or reddish brown. The quartzite rarely occurs in definite beds but more commonly in irregular patches, evidently formed by weathering processes. Much of the rock is dolomitic and on metamorphism becomes a granular white tactite like the upper member of the Agrigo. The "quartzite marker" distinguishable in some parts of the Johnson district is an unaltered remnant of the unit.

Upper member (consisting of units 4 through 7).

Unit 3 (sandy and silty dolomite, 30 to 55 ft thick).—Unit 4 consists of sandy and silty dolomite in beds 1 to 3 feet thick. The silt and sand are irregularly distributed in some of the beds, as shown in figure 11. The sand weathers reddish brown and is in relief, in contrast to the gray dolomite groundmass. On metamorphism the whole unit readily alters to white tactite which is distinguishable from the other tactites only where the peculiar pattern of sand seams is retained. (See fig. 12.) The pattern is commonly seen on weathered surfaces but is seldom evident in the fresh rock.

Unit 5 (dolomite with quartz geodes, 25 to 40 ft thick).—Unit 5 is moderately fine grained silty dolomite in beds generally less than a foot thick. Small quartz geodes are common. An *Atrypa* horizon is common at or near the base. After metamorphism, the upper and less silty part of the unit is generally represented by a layer known as the "upper serpentine marker" consisting of serpentinous marble with metageodes of tremolite. (See figs. 13, 14.) The lower part is generally represented by granular white tactite which locally shows the outlines of geodes. At some places, there is an alternation of serpentinous marble and white tactite.

Unit 6 (stylolitic dolomite, 40 to 100 ft thick).—Unit 6 is creamy-gray granular dolomite, in 1- to 2-ft beds. Rusty stylolite seams are abundant. It is more resistant than most of the other units, forming good outcrops and even cliffs. The thickness varies considerably; and, unlike the thickness variations of the lower units, these variations are seldom compensated by an inverse variation in adjacent beds. The local thinning of unit 6 may be due to the solution and removal of rock indicated by the stylolites, but no correlation between the abundance or thickness of stylolites and the thickness of the unit is evident. Unit 6 is recrystallized but generally not otherwise altered by metamorphism.

FIGURE 11.—Unit 4 of Martin formation showing dolomite with irregularly distributed sand weathering in relief, 4000 feet west of Moore shaft.

Unit 6A (thin-bedded silty dolomite, as much as 30 ft thick).—Unit 6A, which was found in only a few sections, consists of dark-gray to black dolomite, which weathers brown. The beds are lenticular and only 1 to 3 in. thick. Fossils of brachiopods, bryozoans, and corals are abundant but generally poorly preserved. The unit seems to be present near Johnson where it is generally dedolomitized; near the Mammoth mine it has been decomposed for some distance below the surface to a soft yellow chalklike substance consisting mainly of calcite and tremolite.

Unit 7 (reddish shale, 20 to 35 ft thick).—Unit 7 is red to red-brown dolomitic shale, which contains some sandy beds. Poorly preserved fragments of fish teeth or plates have been found at several places in a sandstone layer at the base. The unit, where unmetamorphosed, is easily eroded and generally poorly exposed; but it is persistent and commonly reflected

FIGURE 12.—White tactite derived from sandy dolomite of unit 4 of the Martin formation, near Moore shaft.

FIGURE 13.—Unit 5 of the Martin formation showing geodes of quartz in silty dolomite matrix, 4,000 feet west of Moore shaft.

by a topographic sag. In its metamorphosed condition it is known as the "hornstone marker," and consists of hard gray hornstone with enough disseminated pyrite to cause it to have a rusty-brown weathered surface. Chemical analyses of the unit, and additional details of lithology are presented in an earlier publication (Cooper, 1957).

THICKNESS

We measured nine complete sections of the unmetamorphosed facies of the Martin formation with the following results in feet:

Little Dragoon Mountains: 220, 233, 241, 254, 272.
Gunnison Hills: 219, 257, 258.
Johnny Lyon Hills: 206.
South of Kelsey Canyon: 237.

The type section of the formation near Bisbee is 340 feet thick according to Ransome (1904, p. 33–34). Gilluly (1956, p. 26–27) measured a thickness of 229½ feet at Tombstone and 274½ feet on the west side of the Dragoon Mountains. Thus the thickness in the area of this report is practically the same as in the Tombstone-Dragoon Mountains area but somewhat less than at Bisbee. It is also less than in central Arizona, where the thickness generally ranges from 300 to 400 feet (Huddle and Dobrovolny, 1952, p. 93–109).

FIGURE 14.—Metamorphosed equivalent of bed shown in figure 13. Near Moore shaft. Metageodes of tremolite are embedded in a matrix of tremolite and calcite. Much of the tremolite is serpentinized, and the bed is known as the upper serpentine marker.

The metamorphosed facies near Johnson is 195 to 225 feet thick. This is significantly thinner than the unmetamorphosed facies, suggesting that shrinkage accompanied metamorphism.

AGE AND CORRELATION

The Martin formation is of Late Devonian age and correlates with the Chemung of New York state (Kindle *in* Ransome, 1923, p. 7–8; Stauffer, 1928; Stoyanow, 1936, p. 486–487; Huddle and Dobrovolny, 1952, p. 85–86). The faunal lists given below are for individual collections made in the Dragoon quadrangle and identified by Dr. G. A. Cooper of the U.S. National Museum. The identifying numbers, which are the field numbers of the collections, are used to show their relative stratigraphic position on plate 4.

Rattlesnake Ridge (pl. 4, section 1)

37A Near center sec. 16, T. 14 S., R. 21 E., 25 ft below Martin-Escabrosa contact, from 3-ft sandstone and sandy dolomite bed between units 6 and 7.
- *Atrypa* sp.
- *Theodossia* sp.

Little Dragoon Mountains (pl. 4, section 2)

13aA SW¼ sec. 29, T. 15 S., R. 22 E., unit 6A, 30 to 35 ft below Martin-Escabrosa contact.
- *Aulopora* sp.
- *Phillipsastraea* sp.
- *Thamnopora* sp.
- *Coenites* sp.
- *Synaptophyllum* sp.
- *Atrypa* cf. *A. devoniana* Webster
- *Atrypa* n. sp.
- *Schizophoria* sp.
- "*Spirifer*" cf. *S. orestes* Hall and Whitfield
- *Cyrtina* sp.
- *Stenoscisma* n. sp.

10A NW¼ sec. 16, T. 15 S., R. 22 E., unit 6A, about 50 ft below Martin-Escabrosa contact.
- *Cladopora* sp.
- *Schizophoria* cf. *S. magna* Fenton and Fenton
- *Cyrtospirifer* sp.
- *Cyrtina* sp.

13B SW¼ sec. 29, T. 15 S., R. 22 E., unit 6A, 35 to 55 ft below Martin-Escabrosa contact.
- *Theodossia hungerfordi* (Hall)

13A SW¼ sec. 29, T. 15 S., R. 22 E., unit 6, 55 to 65 ft below Martin-Escabrosa contact.
- *Atrypa* cf. *A. devoniana* Webster

5G SE¼ sec. 21, T. 15 S., R. 22 E., unit 5, 130 ft above Abrigo-Martin contact.
- *Atrypa* aff. *A. devoniana* Webster

Gunnison Hills (pl. 4, section 4)

46C NW¼SE¼ sec. 9, T. 16 S., R. 23 E., unit 6, 240 ft above Abrigo-Martin contact.
Atrypa cf. *A. devoniana* Webster

46B NW¼SE¼ sec. 9, T. 16 S., R. 23 E., unit 6, 230 ft above Abrigo-Martin contact.
Atrypa cf. *A. devoniana* Webster

45B NW¼SW¼ sec. 4, T. 16 S., R. 23 E., 100 to 103 ft above Abrigo-Martin contact.
Alveolites sp.
Thamnopora sp.

14D SE¼SW¼ sec. 4, T. 16 S., R. 23 E., 98 to 102 ft above Abrigo-Martin contact.
Alveolites sp.
Synaptophyllum sp.
Crinoid stems
Atrypa cf. *A. devoniana* Webster

46A NW¼SE¼ sec. 9, T. 16 S., R. 23 E., 65 to 72 ft above Abrigo-Martin contact.
Phillipsastraea sp.
Synaptophyllum sp.
Atrypa cf. *A. devoniana* Webster

14C SE¼SW¼ sec. 4, T. 16 S., R. 23 E., 50 ft above Abrigo-Martin contact.
Atrypa cf. *A. devoniana*

14B SE¼SW¼ sec. 4, T. 16 S., R. 23 E., unit 1, 16 ft above Abrigo-Martin contact.
Macgeea sp.
Atrypa cf. *A. devoniana* Webster

45A NW¼SW¼ sec. 4, T. 16 S., R. 23 E., unit 1, 9 to 12 ft above Abrigo-Martin contact.
Phillipsastraea sp.
Synaptophyllum sp.
Atrypa cf. *A. devoniana* Webster

The Martin formation has been recognized as far north as central Arizona (Huddle and Dobrovolny, 1952, p. 73) and as far west as Devonian rocks are found in southwestern Arizona. Along the eastern boundary of the State, Devonian rocks differ from the Martin in lithology and have been given other names—the Morenci shale of Lindgren (1905, p. 69) in the Clifton-Morenci district, the Portal formation of Sabins (1957, p. 475–480) in the Chiricahua and Dos Cabezas Mountains, and the Swisshelm formation of Epis, Gilbert, and Langenheim (1957) in the Swisshelm and Pedregosa Mountains. The Martin formation correlates with the Swisshelm and Portal formations and, without much question, with the Morenci shale. In southwestern New Mexico is the Percha shale, which is similar in lithology to the Portal formation and the Morenci shale. The Percha is generally considered younger than the Martin.

The uppermost beds of the Martin, which Stoyanow (1936, p. 489–492) distinguished under the working term "Lower Ouray formation," may have a bearing on relations between the Martin and Percha. These beds, which Stoyanow reported from the Little Dragoon Mountains to the upper basin of the Salt River (Stoyanow, 1942, p. 1271), are described as shale, sandstone, and limestone containing *Camarotoechia endlichi* (Meek) and fish teeth. Stoyanow (1936, p. 489) believed that the beds are distinctly younger than the typical Martin and are equivalent to the Elbert and lower part of the Ouray formations of Colorado. As represented in the Little Dragoons, the beds are evidently those identified in this report as unit 7, in which we found poorly preserved fish remains but no other fossils. The rather abrupt changes in thickness of unit 6 and the local presence of unit 6*A* beneath the uniform and persistent unit 7 could be interpreted as due to a time break during which the older beds were eroded. As far as our paleontologic data go, unit 7 could be in part a Percha equivalent, or even as young as Early Mississippian. There is no evidence of an unconformity between unit 7 and the Escabrosa limestone, which at some places seem to grade into one another.

MISSISSIPPIAN SYSTEM

ESCABROSA LIMESTONE

The name Escabrosa limestone was given by Ransome (1904, p. 42) to the limestone of Mississippian age of Escabrosa ridge near Bisbee, and it was later extended by him (Ransome 1916, pl. 25) into the Tombstone district. Stoyanow (1936, p. 508) used the name for the Lower Mississippian strata in all parts of southeastern Arizona. In recent mapping by the Geological Survey, the name has been used in the Dragoon Mountains and in the Globe-Miami area.

The Escabrosa limestone is widely exposed and generally conspicuous topographically in the Dragoon quadrangle. In the Little Dragoon Mountains it forms prominent ridges and cliffs and also the two highest peaks of the quadrangle, Lime Peak and Johnson Peak. In the western part of the area, it supports the higher hills south and east of Keith Ranch as well as the highest ridges in the long line of Paleozoic hogbacks extending northward almost to Kelsey Canyon. The lower contact of the formation is generally well marked topographically because of the inferior resistance of the Martin. The upper contact is not so clearly expressed because the overlying Black Prince and Horquilla limestones are also resistant formations, though not so resistant as the Escabrosa.

There are exceptions to the general topographic expression in some parts of the area. Near Johnson and at several other localities within half a mile of the Texas Canyon quartz monzonite stock, the Escabrosa forms lowlands rather than topographic eminences. This is because the formation has been recrystallized and weakened by metamorphism, whereas the adjacent formations have been hornfelsed and made more resistant. The Escabrosa as represented at the north end of the Dragoon Mountains is also recessive topographically, perhaps for the same reason although hornfelsing of the adjacent formations is not conspicuous in that area. The Gunnison Hills are capped by the Naco group, and the Escabrosa crops out on the nearly uniform western slope. The lack of characteristic topographic expression here seems to be due largely to relatively recent upfaulting of the range.

STRATIGRAPHY

The Escabrosa limestone of the Bisbee area is described (Ransome, 1904, p. 42–54) as characteristically thick-bedded white to light-gray coarse-grained limestone made up largely of crinoid fragments, without interbeds of shale or sandstone and with little or no dolomite. The formation is generally similar but contains considerable dolomite in the lower part in the Tombstone Hills-Dragoon Mountains area and in the area of this report (Gilluly and others, 1954, fig. 4). In the Dragoon quadrangle, the Escabrosa is approximately two-thirds limestone and one-third dolomite, and has two characteristic dolomite members at the base. Immediately above the Martin formation are 50 to 70 feet of fine-grained light- to brownish-gray dolomite weathering to a smooth surface. The rock is in 1- to 3-foot beds and resembles the Martin lithologically. Above the smooth-weathering dolomite are 40 to 65 feet of thicker bedded and coarser grained dolomite weathering to a granular pitted surface. Dolomite beds are present but generally subordinate to limestone in the rest of the formation. In the Johnny Lyon Hills-Kelsey Canyon area, there are 15 to 25 feet of dolomite at the very top; the highest bed invariably is buff yellow.

Abundant chert in the upper half of the formation forms loaves, pods, and lenses as much as 6 feet long and 1 foot thick. The chert is not uniformly distributed but concentrated in certain beds or zones. In the lower half of the formation, it occurs only as small sparse nodules. Most of the chert masses are rusty brown on weathered surfaces but white or pale-colored on fresh fracture. However, a characteristic blue-black chert zone, brown weathering, with associated silicified horn corals appears repeatedly in the upper 15 feet of the lower dolomite.

The following section is the thickest measured during this survey. Two other sections in the area are published elsewhere (Gilluly and others, 1954, p. 8–9).

Section of the Escabrosa limestone

[West slope of main peak of the Gunnison Hills (NE¼SW¼ sec. 4, T. 16 S., R. 23 E.)]

	Feet
Black Prince limestone (in part):	
Shale, deep-maroon; with light-green mottling. One 6-in. bed of sedimentary breccia with pebbles of chert as much as 1 in. in diameter.	
Escabrosa limestone:	
1. Limestone, pinkish-gray; contains some chert nodules; beds 1 to 3 ft thick. Fossils collected 15 ft below top (USGS 9400–PC): *Camarotoechia*? sp. undet., *Pugnoides*? sp. undet., *Spirifer* cf. *S. tenuicostatus* Hall, *Composita humilis*? (Girty), *Rhipidomella*? sp. undet., "*Spiriferina*" cf. S. *salemensis* Weller, *Dielasma*? cf. *D. formosum* (Hall)	31
2. Dolomite, black, silty; weathers tannish-red; a few limestone beds and some chert in small nodules; beds 6 to 12 in. thick. Some beds slightly shaly	22
3. Limestone, light-gray; irregular lenses of dolomite and nodules of chert. *Camarotoechia*? sp. undet. and *Punctospirifer*? sp. undet. collected in upper 5 ft (USGS 9199–PC)	64
4. Limestone, light-gray; in part crinoidal; beds 3 to 5 ft thick; little or no chert	82
5. Dolomite, light-gray; in beds 1 to 2 ft thick; many chert nodules	11
6. Limestone, light-gray, in beds 1 to 3 ft thick; many chert nodules	8
7. Limestone, massive-bedded; has a mottled blue-gray weathered surface; little or no chert. Contains fragments of cup and syringoporoid corals, crinoids, and brachipods. Forms cliff	49
8. Limestone, light bluish-gray; contains nodules and lenses of chert; beds 2 to 3 ft thick. Contains fragments of horn corals and crinoids	26
9. Dolomite, light-gray, fine-grained; contains many elongate nodules and bedded lenses of brown-weathering chert; dolomite beds 1 to 2 ft thick; chert lenses as much as 6 in thick	36
10. Limestone, light-gray, crinoidal; contains many chert nodules as much as 1 ft thick and several feet long. Chert nodules are brown on weathered surfaces but light gray on fresh fracture. Limestone beds 2 to 5 ft thick. Forms steep slope	87
11. Limestone, light-gray, fine-grained; in 1- to 4-ft beds. Members 11 to 17 carry very minor amounts of chert	53
12. Dolomite, light-gray	6
13. Limestone, light-gray to white	53
14. Dolomite, light-gray; in 1- to 3-ft beds	16
15. Limestone, light-gray; in 1- to 3-ft beds	12
16. Dolomite, light-gray; in 1- to 3-ft beds	6
17. Limestone, light-gray; weathers to satiny surface; beds 2 to 4 ft thick	27
18. Dolomite, light-blue-gray; weathers to slightly pitted surface; upper 20 ft contains brown chert nodules	50
19. Limestone, recrystallized; weathers to satiny surface; irregular chert nodules at top; beds 2 to 4 ft thick	10
20. Dolomite, light-gray; weathering to granular pitted surface; beds 2 to 3 ft thick	40
21. Dolomite, light-gray, fine-grained; weathering to smooth surface; lower contact gradational over 2 or 3 ft and bottom several feet of dolomite is reddish-tan	66
Thickness of Escabrosa limestone	755

Section of the Escabrosa limestone—Continued

	Feet
Martin limestone (in part):	
Shale, reddish-gray, fissile	15

The overlying Black Prince limestone is much like the Escabrosa lithologically except that it has a more pink color and a basal bed of shale and conglomerate. The shale bed provides a good marker for separating the two formations and is present in the Johnny Lyon Hills-Kelsey Canyon area, in the Gunnison Hills, and in the northern part of the Little Dragoon Mountains. Where the marker is absent, the formations are not separable with certainty. Southwest of the Centurion mine the Black Prince limestone has been mapped, doubtfully, on the basis of stratigraphic position and a few outcrops of hornfels which apparently represent the shale bed. In the main Dragoon Mountains, the Black Prince limestone has not been recognized.

The formations other than the Black Prince are not likely to be mistaken for the Escabrosa except in small outcrops. The dolomite of the Martin formation is difficult to distinguish in small fault blocks from that of the Escabrosa, unless some of the characteristic Escabrosa chert is present. Some small units in the Naco group resemble the Escabrosa lithologically but these units are generally distinguishable by associated shally or sandy beds and by characteristic fossils, particularly fusulinids.

Near Johnson and elsewhere near the Texas Canyon quartz monzonite stock, the Escabrosa is recrystallized and locally dedolomitized but it lacks the bands of hornfels that occur in all the other carbonate formations. The only silicate minerals ordinarily seen are in knots and lenses representing original chert nodules and in scarce narrow seams along fractures.

The formation has responded to deformational movements in several ways. In the zone of steep thrusts at the north end of the Dragoon Mountains, the rock has flowed and recrystallized to form zones of medium- to coarse-grained marble, one of which has been quarried commercially on a small scale. In the flat thrust plate exposed 2 miles east of Keith Ranch, the formation is thoroughly brecciated and consists of limestone, dolomite, and chert as angular fragments as much as 5 feet in diameter tightly bound together by an abundant matrix of finely milled carbonate. There is no evidence of recrystallization of the carbonate material, nor of plastic flowage in any of the larger blocks, which still contain their bedding structures, chert nodules, and fossils undisturbed. The breccia above the limiting thrust is 500 feet thick and includes a part of the Black Prince limestone in its upper part. The basal maroon shale of that formation has been thinned, mixed with limestone and dolomite fragments, and literally squirted into the surrounding breccia. Nevertheless it is possible to follow its brilliant trace nearly continuously (pl. 1, fig. 27). The structural behavior of the Escabrosa in the Dragoon Mountains and east of Keith Ranch are extremes. In other thrust zones the formation has behaved as a competent unit without evident flowage or brecciation. The differences in behavior are probably a function of confining pressure, temperature, and stress conditions at the time of metamorphism.

Thickness.—Darton (1925, p. 66) stated that the total thickness of the Escabrosa is between 600 and 800 feet, and Gilluly (1956, p. 31–32) measured a thickness of 786 feet in the Tombstone Hills and 729 feet at the north end of the Dragoon Mountains. Our measurements are 585 feet in the Little Dragoon Mountains, 594 feet in the Johnny Lyon Hills, and 755 feet in the Gunnison Hills.

Age and correlation.—The following fossils were collected from the Escabrosa limestone in the Dragoon quadrangle:

Agaricocrinus sp.
Caninia cf. *C. arcuata* Jeffords
Amplexoid? coral indet.
Zaphrentoid coral indet.
Syringoporoid coral sp. indet.
Archimedes (medium-sized screw)
Dielasma? cf. *D. formosum* (Hall)
Rhipidomella? sp. undet.
Pugnoides? sp. undet.
Composita humilis (Girty)?
Camarotoechia? sp. undet.
Punctospirifer? sp. undet.
Spirifer centronatus Winchell
Spirifer cf. *S. tenuicostatus* Hall
"*Spiriferina*" cf. *S. salemensis* (Weller)

The corals were identified by Helen Duncan, the crinoid by Edwin Kirk, and the other forms by James Steele Williams, all members of the Geological Survey. Concerning the fauna Mr. Williams stated (written communication, July 28, 1947), "The studies show the presence of an Escabrosa fauna represented by several small collections, each containing but a few species, some of which are, however, diagnostic. This fauna ranges from upper Kinderhook or lower Osage, possibly into the lower Meramec." A more comprehensive discussion of the faunas is presented elsewhere (Gilluly and others, 1954, p. 11–12).

The correlation of the Escabrosa limestone with other formations of Mississippian age in North America is given in a publication under the auspices of the National Research Council (Weller and others, 1948, p. 136, pl. 2). Its correlatives in southeastern Arizona consist of the lower part of the Tornado limestone in the Globe-Ray region (Ransome, 1916, p. 142–143) and the Modoc and lower part of the Tule Spring limestone of the Clifton-Morenci area (Lindgren, 1905,

p. 69–72). In northern Arizona it is represented by the Redwall limestone, which according to Huddle and Dobrovolny (1945) is continuous with the Escabrosa through the eastern part of the State. In southwestern New Mexico it is represented by much or all of the Lake Valley limestone and perhaps the Kelly limestone.

MISSISSIPPIAN OR PENNSYLVANIAN SYSTEM

BLACK PRINCE LIMESTONE

The Black Prince limestone was named from exposures near the Black Prince mine in the Johnson Camp mining district (Gilluly and others, 1954, p. 13). Because of metamorphism at that locality the type section was measured on the west slope of Gunnison peak 4½ miles southeast of the mine.

The Black Prince limestone crops out on the northeast and southeast flanks of the Little Dragoon Mountains, along the main ridge of the Gunnison Hills, and in the Kelsey Canyon-Johnny Lyon Hills area. It has not yet been recognized in the Dragoon Mountains, but equivalent beds may occur in the upper part of the Escabrosa limestone as there defined (Gilluly and others, 1954, p. 5).

Though not intrinsically weak, the Black Prince limestone is somewhat less resistant than the Escabrosa and tends to form dip slopes. Both contacts of the formation are marked by zones of weak rocks which generally form grassy swales or saddles between limestone outcrops. The lower part of the formation is involved in the plate of tectonic breccia 2 miles northeast of Keith Ranch, and it makes up the crowning 30 to 50 feet of the cliffs at the northwest end of the breccia mass.

STRATIGRAPHY

The Black Prince limestone resembles the Escabrosa but was given separate formational status (Cooper, 1950, p. 32) because J. S. Williams (written communication, July 28, 1947) assigned fossils obtained from it to the Late Mississippian or Early Pennsylvanian—that is, to a distinctly younger epoch than the one to which the Escabrosa has been referred. On a lithologic basis, the Black Prince is separable from the underlying Escabrosa by a basal shale member that contrasts strikingly with the virtually pure limestone above and below. Other distinctive features are a general pink hue, a few partings of red shale between the limestone beds, and local gray limestone mottled with bright tints of yellow, pink, and green.

The basal shale member, 10 to 30 feet thick, is maroon or red and commonly mottled with light green. It is moderately fissile and contains nodules of chert, lenses of chert conglomerate, and locally thin beds of limestone. Much of the chert is greenish white, but over large areas there are also white to flame-orange nodules that are in part a replacement of colonial corals. These colorful and resistant nodules weather out on the surface providing a useful identifying characteristic for the unit. The conglomerate lenses range from a few inches to 3 feet in thickness. They are composed of angular to rounded chert and jasper fragments as much as 2 inches in diameter in a variable matrix of fine-grained silica, calcite, and shale. An excellent exposure of the shale and conglomerate may be seen in a prospect shaft on the bank of Tres Alamos Wash 3½ miles south of Deepwell Ranch.

The limestone, overlying the shale, is in 1- to 4-foot beds. In the Johnny Lyon Hills-Kelsey Canyon area it is in part oolitic and ranges from dark gray to gray mottled with bright tints of yellow, pink, and green. In the Little Dragoon Mountains and Gunnison Hills it is more uniform and seems to show more recrystallization. There it is typically light pinkish gray in the lower part and becomes increasingly pink toward the top. Fossils are scarce and were found in the lower part only. Chert is present in small sparse nodules. The limestone is in sharp but apparently conformable contact with the overlying shale at the base of the Horquilla limestone of the Naco group.

The following section, which is a continuation of the one given on page 57, is the type section of the Black Prince limestone. Two additional sections from the Dragoon quadrangle are published elsewhere (Gilluly and others, 1954, p. 14).

Section of the Black Prince limestone

[West slope of main peak of the Gunnison Hills (NE¼SW¼ sec., 4, T. 16 S., R. 23 E.)]

	Feet
Horquilla limestone (in part):	
Shale, maroon; with lenses and beds of mottled blue, pink, and white limestone.	
Black Prince limestone:	
Limestone, light pinkish-gray; becomes increasingly pink in upper part; contains scarce chert nodules; lenses of shale in lower 15 ft. Fossils collected 25 to 30 ft above the base (USGS 9401-PC): *Spirifer* cf. S. *pellaensis* Weller, *Composita humilis* (Girty)? *Linoproductus* sp. undet., *Punctospirifer*? sp. undet., Gastropoda, indet	102
Shale, deep-maroon; with light-green mottling; contains scattered nodules of chert and one 6-in. bed of sedimentary breccia with chert fragments as much as 1 in. in diameter	17
Thickness of Black Prince limestone	119
Escabrosa limestone (in part):	
Limestone, pinkish-gray; with chert nodules (bed 1, p. 57).	

In metamorphic areas, most of the Black Prince limestone is represented by uniform light-gray to white marble. The basal shale is represented by granular hornfels, which is conspicuous near Johnson because it weathers rusty brown in contrast to the light-colored marble above and below. Many prospect pits and shafts are located along it. The Black Prince is distinguished from the overlying Horquilla limestone by the absence of thin bands of silicate rock which characterize the Horquilla in metamorphic areas.

Thickness.—Measurements of the thickness of the Black Prince limestone range from 119 feet in the Gunnison Hills to 168 feet south of Kelsey Canyon. The average in the Little Dragoons is about 130 feet.

Age and correlation.—Fossils are neither abundant nor well preserved in the Black Prince limestone. The following forms were collected, all from the lower 60 feet of the formation:

Lithostrotionella sp. undet.
Triplophyllites? sp. B
Glyptopora n. sp.
Juresania? sp. undet. (*Pustula*?)
Linoproductus altonensis (Norwood and Pratten)
L. sp. undet.
Camarotoechia? cf. *C. tuta* (Miller)
C. ? sp. undet.
Spirifer cf. *S. pellaensis* Weller
Composita humilis (Girty)?
Punctospirifer? sp. undet.
Pectinoid pelecypod
Gastropods, indet.

The identifications were made by Helen Duncan (corals and bryozoans) and James Steele Williams (brachiopods and pelecypods) of the Geological Survey and by J. Brookes Knight (gastropods) of the National Museum.

In a preliminary report Mr. Williams said (written communication, July 28, 1947),

A series of collections * * * is either of Late Mississippian or Early Pennsylvanian age. If Late Mississippian, they would probably represent the Paradise, but the forms composing the collections are too few and too fragmentary to allow definite age assignment. I would be slightly more inclined to classify these as Mississippian than as Pennsylvanian, but any conclusion either way would be a very shaky one.

After further study of the upper Paleozoic faunas of the region he wrote (Gilluly and others, 1954, p. 15),

To the writer, the * * * collections, when taken together, have a Mississippian facies (a late Osage or younger facies) * * * *Linoproductus altonensis* (Norwood and Pratten), * * * the *Lithostrotionella*, and the general assemblages suggest that the Black Prince is a lithologic facies that may be of an age equivalent to the part of the Escabrosa that is present locally and that is thought to be of late Osage or early Meramec age. It is also probably equivalent to beds in the lower part of the Paradise formation, although it may be slightly older. At least one collection suggests that beds of Pennsylvanian age might locally be included in the Black Prince, but the evidence for this hypothesis is not at all strong.

The Paradise formation, with which the Black Prince may be permissively but not conclusively correlated, was named by Stoyanow (1926) in the Chiricahua Mountains about 45 miles east of the Dragoon quadrangle. The formation has not been recognized farther west and, judging from published descriptions by Hernon (1935, p. 657–658), is different lithologically from the Black Prince.

PENNSYLVANIAN AND PERMIAN SYSTEMS

NACO GROUP

The name Naco limestone was proposed by Ransome (1904, p. 44–45) for the limestone of supposedly Pennsylvanian age above the Escabrosa limestone and below the unconformable Cretaceous rocks in the Bisbee area. According to Girty (Ransome, 1904, p. 46–54; Ransome, 1916, p. 149), the fossils from the lower part of the Naco limestone are of early (Early and Middle of present usage) Pennsylvanian age and those from the upper part suggest those of the upper part of the Hueco limestone of Texas, once assigned to the Pennsylvanian but now classed as Permian by the Geological Survey. Stoyanow (1936, p. 522–523) proposed that the name Naco limestone be restricted to the lower part of the formation as described by Ransome—that is, to the part which contains the Middle Pennsylvanian fauna. As pointed out elsewhere (Gilluly and others, 1954, p. 16), the Geological Survey has adopted Naco as a group name for the post-Mississippian Paleozoic rocks. The divisions so far recognized (Gilluly and others, 1954, p. 16) with their approximate thicknesses in the Dragoon quadrangle are as follows:

	Feet
Walnut Gap volcanics:	
Naco group:	
Concha limestone	130
Scherrer formation	690
Epitaph dolomite	0—?
Colina limestone	440+
Earp formation	1, 130
Horquilla limestone	1, 600
Black Prince limestone.	

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Horquilla limestone is the most widely exposed formation of the Naco group. It forms the south rim of Kelsey Canyon and generally extends in a nearly continuous outcrop southward to the vicinity of the Willcox-Cascabel road. It reappears from under the alluvium at the north end of the Little Dragoon Mountains and is exposed at intervals southeastward, past Johnson, to the Legal Tender prospect. A complete section is found on the main ridge of the Gunnison Hills. Parts of the formation crop out also in the thrust zones at the north end of the Dragoon Mountains, west of Dragoon, in the lower part of Sheep Basin, and east of Keith Ranch.

The higher formations of the Naco group are of progressively more restricted occurrence. A complete section of the Earp formation is found on the main ridge of the Gunnison Hills, and parts of the formation crop out in the faulted areas at the north end of the Dragoon Mountains, west of Dragoon, and along Tres Alamos Wash east of Keith Ranch. The Colina limestone is exposed on both sides of Walnut Gap in the Gunnison Hills and in a small outcrop at the extreme north end of the Dragoon Mountains. The Epitaph dolomite is confined to fault slices at the north end of the Dragoon Mountains beneath the unconformable Glance conglomerate. In the Gunnison Hills the Scherrer formation rests directly on the Colina. The Scherrer formation and the Concha limestone crop out only in that part of the Gunnison Hills lying northeast of Walnut Gap.

All the Naco formations except the Earp are ridge forming at least locally. In deeply eroded areas the Horquilla limestone generally forms the foot of dip slopes of the Black Prince limestone, but this is due largely to a zone of weak rocks at the bottom of the Horquilla and not to weakness of the Horquilla as a whole. In the main hogback ridge of the Gunnison Hills, the Escabrosa, Black Prince, and Horquilla form a nearly uniform slope, and the Horquilla caps the highest peak. The Horquilla also makes conspicuous ridges and peaks on the south side of Kelsey Canyon. The topographic surface on the Horquilla lacks the cliffs formed by the Escabrosa but is, instead, "ribbed" at short and fairly regular intervals by low ridges or ledges of limestone. Somewhat similar ribbed surfaces are also formed by the Earp formation and the Colina limestone but are not formed by the older formations. This commonly permits recognition of the Naco group at a distance.

The Earp formation is nonresistant and generally gives rise to lowlands with numerous outcrops of reddish-brown to orange beds which are conspicuous, even at a distance. The Colina limestone forms a surface resembling the Horquilla but commonly forms bolder outcrops with a dark-gray to almost black color. The Epitaph dolomite, which is not known north of the Dragoon Mountains, consists of a cliff-making dolomite at the base overlain by relatively nonresistant rocks. The sandstone making up most of the Scherrer formation is resistant and generally weathers rusty brown; the basal siltstone member is nonresistant and forms a bench; a thick gray limestone member, also nonresistant, occurs in the sandstone in the upper middle part of the formation. The Concha limestone, although easily recognized by fossils and details of lithology, is not easily identified at a distance except by its position above the Scherrer formation.

HORQUILLA LIMESTONE

The Horquilla limestone was named by Gilluly (Gilluly and others, 1954, p. 16) in the Tombstone Hills where it is described as a series of thin-bedded blue-gray limestones with a few limestone beds as much as 6 or even 8 feet thick; in the upper part, there are thin beds of red shale and shaly limestone. The base is an obscure surface of disconformity, which Gilluly did not locate more closely than within a score of feet stratigraphically. The top was taken arbitrarily where the thin shaly limestone and red shale making up the lower part of the Earp formation become dominant over the more massive limestone characteristic of the Horquilla.

In the area of this report the base of the Horquilla was taken at the bottom of a weak shale zone 30 to 65 feet thick lying immediately above the Black Prince limestone as defined. This zone, which generally forms topographic sags, provides a very satisfactory basis for mapping. In the Gunnison Hills, it is made up of dull-red shale with subordinate interbeds of mottled blue, pink, and white limestone. It resembles the shale member at the base of the Black Prince limestone but lacks the distinctive chert nodules of that unit. Although the zone seems to be completely nonfossiliferous at most places, recognizable Pennsylvanian fossils (fusulinids) were found southeast of Keith Ranch in thin flaggy limestone within the lower 10 feet of the unit. This indicates that our assignment of the unit to the Horquilla is correct. The break between the Black Prince fauna and the Horquilla fauna could fall anywhere between the shale zone and a horizon about 100 feet down in the limestone assigned to the Black Prince.

Above the basal shale unit and constituting most of the formation are limestone and very subordinate clastic beds which weather to the ribbed surface previously described. The limestone is predominantly fine grained and pinkish gray to blue gray mottled with black; it occurs in beds that are generally a foot or two thick and only rarely less than 6 inches or more than 3 feet thick. There are a few coarse-grained gray limestone beds that resemble the Escabrosa and also a few very fine grained partly dolomitic beds that weather to tan or light-brown. Much of the limestone is fossiliferous and contains fusulinids, productid and spiriferoid brachiopods, gastropods, corals, and fragments of crinoids. Abundant beds loaded with fusulinids are very helpful in distinguishing the Horquilla from the Escabrosa and Black Prince limestones which lack these fossils. Fusulinid beds are also characteristic of the lower member of the Earp formation but have not been found above that member, within the area of this report.

Nodules and lenses of chert are common in the Horquilla limestone. They are most commonly blue black with rusty exteriors but are also white, gray, and in certain zones a brick red. The nodules are rarely more than a foot long or 3 inches thick, in contrast to the much larger chert nodules of the Escabrosa limestone. There seems to be a complete gradation from nodules of solid chert to those consisting of a surface skin of chert surrounding a limestone core.

In all sections of the formation there are many short covered intervals corresponding to sags in the ribbed surface. The concealed parts are layers or partings of soft rock the nature of which is generally not apparent. Where exposed they generally consist of olive-green or pink shale in layers as much as 2 or even 3 feet thick. Beds of calcareous clay are also present although very rarely exposed. Clastic material is not wholly confined to the thin soft beds but is also in scarce 10- to 30-foot zones of fissile silty or sandy limestone, thin-bedded calcareous siltstone, and, near the top of the formation, brown-weathering calcareous sandstone.

The clastic beds are converted by metamorphism to resistant hornfels and in this condition are conspicuous. Abundant thin bands of hornfels in such areas are the most useful criterion for distinguishing the formation from the Escabrosa and Black Prince limestones, which, except for the shale bed at the base of the Black Prince, do not give rise to silicate bands.

The following section is the only section of the entire formation measured in the area of this report.

Section of the Horquilla limestone

[Main ridge of Gunnison Hills, ¼ mile north of main peak (northern part of sec. 4, T. 16 S., R. 23 E.)]

	Feet
Earp formation:	
Limestone, blue-gray; contains abundant fusulinids—*Triticites ventricosus* (Meek and Hayden) var.	
Covered interval	176
Horquilla limestone:	
1. Limestone, light- to blue-gray; like unit 9 except virtually free from chert. USGS 9402F–PC contains: *Triticites* sp. indet., Calcitornellid Foraminifera, crinoid stems	37
2. Covered	47
3. Limestone like unit 9 but perhaps lighter gray and pinker on fresh fracture. *Syringopora* sp. B collected 155 ft above base (USGS 9402D–PC); *Triticites* sp., *Syringopora* sp. C?, *Multithecopora*? sp. B collected 270 ft above base (USGS 9402E–PC)	360
4. Limestone, sandy; fresh fracture dark-gray; weathered surface brown; USGS 9402C–PC contains: *Triticites* sp., *Punctospirifer kentuckyensis* (Shumard), *Dielasma bovidens* (Morton), crinoid stems	2
5. Limestone, like unit 9	293
6. Limestone, like unit 9 except that light-gray fine-grained and partly dolomitic beds are fairly conspicuous (similar beds present but scarce below)	75
7. Limestone, like unit 9; USGS 9402A–PC, from 115 to 135 ft above base, contains *Caninia* sp. A., syringoporoid coral, genus indet., *Composita subtilita* (Hall), *Echinoconchus*? *semipunctatus* (Shepard)?, *Myalina*; USGS 9402B–PC, from top 30 ft, contains *Phricodothyris*? sp. undet., *Composita subtilita* (Hall)?, *Dictyoclostus* cf. *D. coloradoensis* (Girty), *Marginifera wabashensis* (Norwood and Pratten)?, *Hustedia mormoni* (Marcou)	215
8. Shale, light-tan to reddish-brown, calcareous	30
9. Limestone, blue-gray; commonly with pink, tan, or dark-gray mottling, mostly fine-grained but some beds coarse-grained fossiliferous; contains white to blue-black chert nodules weathering brown (some larger than 1 by 3 ft but most are smaller); limestone beds 1 to 3 ft thick except for scarce beds as much as 5 ft thick; a few 1- to 3-ft beds of olive-green shale. The unit forms a ribbed surface due to the presence of ledge-forming limestone beds at fairly regular intervals. Fossils collected about 300 ft above base (USGS 9402–PC): *Wedekindellina excentrica* (Roth and Skinner), *Fusulina distenta* (Roth and Skinner) possibly *F. novamexicana* (Needham), crinoid stems	425
10. Siltstone, olive-green; in beds less than 6 in. thick; weathers into angular blocks; one 2-ft limestone bed near base	17
11. Limestone, like unit 9; fusulinids in lowest bed	54
12. Shale, maroon to purple with nodules and beds of limestone; in part covered	40
Thickness of Horquilla limestone	1, 595
Black Prince limestone:	
Limestone, pinkish-gray.	

Thickness.—The type section of the Horquilla limestone near Tombstone is 999 feet thick (Gilluly and others, 1954, p. 17). The top of this section is eroded, but Gilluly believed that less than 200 feet of beds is missing and that the formation is about a thousand feet thick in the Tombstone-Dragoon Mountain area. The following measurements indicate a somewhat greater thickness:

	Feet
Little Dragoon Mountains (partial because top concealed)	1, 050
Johnny Lyon Hills (partial because top concealed)	1, 325
Gunnison Hills (complete)	1, 595
Near Portal in the Chiricahua Mountains (Sabins, 1957, p. 487)	1, 605

EARP FORMATION

The Earp formation, named by Gilluly (Gilluly and others, 1954, p. 18) in the Tombstone Hills, is distinguished from the Horquilla limestone by the presence of many beds of shale, calcareous sandstone and marl, and a few thin but conspicuous beds of tan- or orange-weathering dolomite. About half the formation is limestone, which ranges from fine to coarse grained and from almost white through grays tinted or mottled by blue, red, or tan to almost black. The shale is green, red, or purple. The sandstone is gray but weathers to a conspicuous brown. The various rock types alternate with one another in units from a foot to a few tens of feet thick, giving rise to a more diversified lithologic assemblage than any other formation of the area.

Although the formation is distinctive lithologically, there is no evidence, either paleontologic or stratigraphic, of a break in sedimentation at either the top or the bottom. Both contacts are arbitrary divisions in a transitional series. Fortunately the transitions are abrupt enough to limit the selection within a few score of feet stratigraphically. At most places nearly all geologists would pick the same contact. It is improbable, however, that any plane selected can be recognized over a wide area. In the type section, Gilluly (Gilluly and others, 1954, p. 19) selected the top of the highest orange-weathering dolomite as the top of the formation. In the area of this report, the highest "orange dolomite" is about 100 feet down in the zone characterized by abundant clastic beds and the top of the formation is marked by a conspicuous brown-weathering sandstone.

Beds of intraformational conglomerate are fairly abundant in the Earp formation. Most of them consist of fragments of the underlying bed and mark no detectable break in lithology or type of fossils. Probably their only significance is to show that the Earp was deposited in shallow water, turbulent enough at times to break up and abrade the partly consolidated deposits previously laid down. In the Gunnison Hills section, given in detail below, there is a conglomerate bed (unit 35) which seems to fall in a different category. It consists of a heterogeneous mixture of sandstone, limestone, and chert fragments with diverse colors and textures. Many of the fragments are evidently derived from the beds immediately below, but some can be matched only scores of feet lower in the section, and others, particularly small round jasper fragments, cannot be certainly matched with any of the underlying rocks. Below the conglomerate the limestone is light in color and contains many large fusulinids; above the conglomerate the limestone is mostly dark gray or black and contains a poorly preserved gastropod-cephalopod fauna resembling that in the Colina limestone. No fusulinids have been found above the conglomerate.

The conglomerate within the Earp of the Gunnison Hills marks a break in the sedimentation history of local and possibly regional significance. Although the importance of the break cannot be evaluated at present, we have divided the formation at a horizon just below the conglomerate in mapping the Gunnison Hills area (pl. 1). The upper and lower members have also been recognized at the north tip of the Dragoon Mountains and in the outcrop along Tres Alamos Wash but are not distinguishable where metamorphism has destroyed the fossils and original color of the rock. Thus the Earp is mapped as a unit in the contact metamorphic zone southwest of the Centurion mine and in the zone of dynamic metamorphism which makes up the marble belt of the Dragoon Mountains. A sheared and recrystallized intraformational limestone conglomerate zone in the Earp has yielded much of the marble quarried commercially.

The conglomerate at the base of the upper member has not been identified positively outside of the Gunnison Hills area but is probably present at the Tres Alamos Wash locality. The Earp formation here crops out in the core of an overturned syncline in one of the thrust plates. The structure is complicated by isoclinal drag folds and by faults, and only 500 or 600 feet of the Earp is present. These beds consist of red and green shale, some thin-bedded siltstone, and sandstone which weather dark brown, and light-colored limestone which contains abundant large fusulinids. Very near the top of the exposed section, a conglomerate appears near the edge of the overlapping alluvium and can be traced about 250 feet before faults displace it back under the alluvium. The conglomerate forms a heterogeneous bed, 1 to 2 feet thick, containing pebbles of chert, jasper, and limestone in a brown silty dolomite matrix. Thus it is similar lithologically to the marker conglomerate at the base of the upper member. Unfortunately, there is not enough exposure of the beds overlying the conglomerate to prove or disprove the correlation. We have, therefore, mapped the entire area as the lower member. If the upper member is present it would cover at most a few hundred square feet.

The following section is the only section of the entire Earp formation in the area of this survey.

Section of the Earp formation

[East side of Gunnison Hills, 1 mile north of main peak (sec. 33, T. 15 S., R 23 E.)]

	Feet
Colina limestone:	
Limestone, dark-gray to blue-black, fine-grained; free from chert; a few short covered intervals which may be marl.	
Earp formation:	
1. Sandstone, fine-grained, calcareous; weathers brown	7
2. Limestone, dove-gray	4
3. Marl, partly covered	4
4. Sandstone, fine-grained, calcareous; weathers brown	1½
5. Covered, probably marl	11

Section of the Earp formation—Continued

		Feet
6.	Limestone, blue-black, fine-grained; contains gastropods; beds mostly less than 1 ft thick	19
7.	Marl, light-gray	11
8.	Limestone, very dark gray to dull black; has thin calcite veins; beds as much as 3 ft thick	20
9.	Covered except for one mottled light- and dark-gray limestone outcrop	14
10.	Sandstone, calcareous; fresh fracture light-gray; weathered surface brown	13
11.	Covered, probably shale or marl	11
12.	Limestone, dark-gray to blue-black; contains irregular seams of red silt	13
13.	Covered	5
14.	Limestone, gray with blue mottling	½
15.	Dolomite, light reddish-tan, fine-grained; contains silty laminae	2½
16.	Covered, probably marl with 6-in. sandstone bed	6
17.	Sandstone, calcareous; fresh fracture gray; weathered surface brown; conspicuous cross-bedding and ripple marks	11
18.	Covered, probably marl	7
19.	Limestone, gray with green mottling; beds 4 to 6 in. thick	9
20.	Limestone, dark-gray; beds 1 to 4 ft thick	13
21.	Dolomite, tan, fine-grained, silty	1
22.	Sandstone, calcareous; weathers brown; beds less than 4 in. thick	4
23.	Marl, light- to pinkish-gray	9
24.	Dolomite, light-tan, fine-grained; contains laminae of silt	6
25.	Limestone, very dark gray; contains gastropod fragments; beds as thick as 1 ft	15
26.	Sandstone, calcareous; fresh fracture gray; weathered surface brown; beds less than 6 in. thick	13
27.	Marl, light-colored	6
28.	Limestone, gray; contains many echinoid spines of *Echinocrinus* (USGS 9404D–PC)	4
29.	Limestone, dark-gray; contains many cephalopods; USGS 9404C–PC contains *Metacoceras* sp., *Mooreoceras* sp., *Perrinites* sp. (or might be *Properrinites*), trilobite, genus indet	7
30.	Limestone, gray, fine-grained; with tan mottling	2
31.	Dolomite, aphanitic; fresh fracture greenish gray; weathered surface brown	1
32.	Mostly covered; a few outcrops of thin-bedded rusty-weathering calcareous sandstone in top 40 ft	56
33.	Sandstone, calcareous, fine-grained; fresh fracture pinkish gray; weathered surface brown; beds less than 3 in. thick	4
34.	Covered	23
35.	Conglomerate; grading upward into sandstone with scattered pebbles; pebbles of sandstone chert, and limestone with diverse colors and textures; sparce cobbles as much as 10 in. across	11
	Thickness of upper member (units 1–35)	344½
36.	Covered, probably marl or clay	16

Section of the Earp formation—Continued

		Feet
37.	Limestone, pink, silty; beds less than 1 ft thick; partly covered	14
38.	Limestone, pinkish-gray; contains chert nodules; 1 ft of tan chert at top; USGS 9404B–PC contains: Fistuliporoid bryozoan, genus indet., *Stenodiscus* n. sp. A, *Polypora*? sp. indet., *Septopora* sp. undet., *Rhombopora*? sp. indet., *Composita*? sp. undet., "*Productus*" s. l. sp. undet	7
39.	Limestone, white to light-gray, fine-grained; beds 4 to 6 in. thick; limestone conglomerate 1 ft thick at base	8
40.	Covered	5
41.	Limestone, pinkish-gray; contains small (⅛ by ¼ in.) brown silica nodules	1
42.	Covered	30
43.	Limestone, pink to blue-gray; irregularly mottled by tan; beds less than 6 in. thick	8
44.	Covered	8
45.	Limestone, blue-gray, dolomitic, very fine grained; with yellow mottling	2
46.	Covered	8
47.	Limestone, pink; with purple mottling	2½
48.	Covered, probably pink shaly limestone	10
49.	Limestone, white with pink mottling; USGS 9404A–PC contains: *Schwagerina* cf. *S. longissimoidea* (Beede), *S.* sp. undet., *Ozawainella* sp	8
50.	Covered, probably pink marl	28
51.	Limestone, light pinkish-gray; with a little yellow mottling; beds as much as 3 ft thick	25
52.	Limestone, dove-gray, fine-grained; contains small chert nodules; beds 1 to 2 ft thick	15
53.	Covered	10
54.	Limestone, blue-gray; contains many fossils especially large spirifers; USGS 9404–PC contains: *Stereostylus*? sp. *B.*, *Echinocrinus*, trepostomatous? bryozoan, genus indet., *Neospirifer kansasensis* (Swallow), *Chonetes granulifer* Owen, *Amphiscapha* sp. undet	13
55.	Covered	11
56.	Limestone, mottled pink and yellow, fine-grained	13
57.	Limestone, dark blue-gray; becomes pinkish-gray near top; seams of red silt; beds 6 to 12 in. thick	19
58.	Covered	10
59.	Dolomite, orange- or tan-weathering, fine-grained; with varvelike laminations	2
60.	Limestone, dove- to pinkish-gray; with a little orange mottling; contains a little orange-weathering chert; USGS 9403D–PC contains *Triticites* aff. *T. tumidus* Skinner, *T. obesus* (Beede)?, *T. ventricosus* (Meek and Hayden) var., *Echinocrinus*, *Neospirifer kansasensis* (Swallow)?	10

Lower part of section measured about a thousand feet farther west. Offset on member 61 which forms a conspicuous ledge between the two parts of the section.

61. Limestone, gray; in beds 2 in. to 2 ft thick except for massive 4-ft bed at the base; the top 2 ft is fine-grained dolomitic limestone

Section of the Earp formation—Continued

	Feet
weathering light reddish-tan and having varvelike laminations and orange chert nodules	36
62. Covered except for several small outcrops of light-colored marl and a 1-ft ledge of tan limestone	40
63. Limestone, gray; USGS 9403C–PC contains *Triticites* sp	2
64. Shale interbedded with reddish-brown (weathered surface) calcareous sandstone; sandstone contains nodules of gray limestone; one 2-ft limestone bed included	30
65. Limestone, pinkish-gray; in beds 1 to 2 ft thick, with two 2-ft layers of pale-green mudstone(?)	28
66. Sandstone, calcareous, fine-grained	14
67. Limestone alternating with covered intervals which may be shale or marl; the limestone (more than 50 percent of whole) is mostly pinkish gray but in part tan and fine-grained	51
68. Sandstone, calcareous, fine-grained; weathers brown and contains several feet of shale at base	25
69. Limestone, gray; in ledges separated by covered intervals which are probably shale; USGS 9403B–PC contains *Neospirifer kansasensis* (Swallow)?, *Composita subtilita* (Hall)	22
70. Shale, calcareous; contains a few ledges of gray limestone as much as 2 ft thick; in part covered	46
71. Limestone, blue-gray; contains many fusulinids; some intraformational conglomerate; beds 6 to 12 in. thick	12
72. Sandstone, calcareous, ripple-marked; weathers rusty brown; some covered intervals which are probably shale or marl	26
73. Limestone, gray, mottled	3
74. Shale, green; has several feet of sandstone at base; partly covered	15
75. Limestone, gray; contains many fusulinids; USGS 9403A–PC contains: *Triticites collumensis* Dunbar and Condra, *T. secalicus* (Say)?, *Dunbarinella*? sp	13
76. Limestone, reddish-tan, fine-grained; contains silica nodules half an inch or less in diameter	1
77. Sandstone, calcareous; weathers rusty-brown, interbedded with minor amount of shale or marl	31
78. Limestone, mottled blue-gray and pink; contains silty layers in upper part; a few light-tan limestone beds; partly covered	84
79. Sandstone, calcareous, fine-grained; fresh fracture gray; weathered surface brown; beds 1 to 12 in. thick	19
Thickness of lower member (units 36–79)	781½
Thickness of Earp formation (units 1–79)	1, 126

Horquilla limestone:

Limestone, blue-gray to gray; mottled with pink; a few fine-grained beds weather light-tan; beds 1 to 3 ft thick.

The Earp formation is very susceptible to thermal metamorphism because it contains so much impure calcareous rock. In the metamorphic zone surrounding the Texas Canyon stock, the outcrops assigned to the Earp contain so much hornfels that they are more similar to parts of the Abrigo and Martin than to the other upper Paleozoic formations. The criteria used for distinguishing the Earp include stratigraphic position, very abundant hornfels, and the fairly common occurrence of pure calcite marble bands, 5 feet or more thick. The chances of misidentification are considerable in small outcrops and in much-faulted areas.

The Earp is less competent than the adjacent formations. Along the whole Dragoon Mountains and in other intensely deformed areas to the south, Gilluly (1956, p. 42) reported that the shale and shaly limestone have been sheared out at many places, and that the formation has been greatly thinned or repeated by dynamic action.

Thickness.—Available thickness measurements of the Earp formation are as follows:

Locality	*Thickness (feet)*	*Source of data*
Earp Hill, near Tombstone	595	Gilluly and others, 1954, p. 20
Near Golden Rule mine, Dragoon Mountains.	577	Gilluly and others, 1954, p. 21
Gunnison Hills	1, 126	This report
Near Portal, Chiricahua Mountains.	2, 710	Sabins, 1957, p.489

The notable thickening of the formation north and east of the type area parallels a less extreme thickening of the Horquilla. The thin and thick sections were farther apart at the time of deposition than they are at present, and have been brought together by thrusts faults of large but unknown displacement.

COLINA LIMESTONE

The Colina limestone was named by Gilluly (Gilluly and others, 1954, p. 23) in the Tombstone Hills where it was described as dark-gray to black limestone lying between the Earp formation and the Epitaph dolomite. He described a local "stray" sandstone bed some distance above the base and a transition to dolomite through a few feet at the top. The rest of the formation is limestone which is uniformly dark gray to black on fresh fracture. Although the dark limestone locally weathers light gray or almost white, it is wholly lacking in truly light-gray or pink limestone beds like those common in the Horquilla limestone and the Earp formation. Another distinguishing feature is the preponderance of fossil snails over fossil brachiopods—a relation which is the reverse of that in the Horquilla limestone.

The Colina limestone as mapped in the area of this report is similar to the type section except for a few dolomitic beds which are light gray on both fresh and weathered surfaces and a few beds of sandstone and shale well up in the formation. As mentioned in describing the Earp formation, the lower boundary was taken arbitrarily just above a brown-weathering sandstone bed at the top of the zone with abundant clastic rocks. The top was taken at the base of a bench-forming red siltstone member, about 65 feet thick, assigned to the Scherrer formation.

There is no complete section of the Colina in the Dragoon quadrangle. A section of the lower part is as follows:

Section of the Colina limestone

[Gunnison Hills, main ridge 2 miles north of main peak (SE¼ sec. 29, T. 15 S., R. 23 E.)]

	Feet
Alluvium.	
Unconformity.	
Colina limestone:	
1. Limestone, nearly black, fine to medium-grained; without chert	47
2. Sandstone, light pinkish-gray, calcareous, thin-bedded (1 to 6 in.); contains some interbedded shale	16
3. Limestone, gray, fine-grained, slightly dolomitic; beds 6 to 12 in. thick	18
4. Sandstone, fine-grained; weathers rusty brown; contains some shale in lower part	8
5. Limestone, fine-grained; contains many gastropods and echinoid spines; lower part dark-gray; upper part weathers to creamy-gray surface; top few feet silty; beds 1 to 2 ft thick	17
6. Limestone, dark-gray to black, fine-grained; without chert; lower part includes a few limestone beds weathering light-gray and one 1-ft sandstone bed; USGS 9405A-PC contains poorly preserved gastropods including *Omphalotrochus* sp. undet	179
7. Limestone, fine-grained, dolomitic; weathers to light-gray surface	32
8. Sandstone fine-grained; weathers reddish brown; partly covered	15
9. Limestone, like unit 7; beds 2 to 12 in. thick	11
10. Limestone, like unit 6; beds as much as 2 ft thick; with some silty partings	98
Thickness of Colina limestone exposed	441
Earp formation:	
Sandstone; weathers reddish brown.	

The upper part of the Colina limestone at this locality is concealed by alluvium, which lies along Walnut Gap, a narrow valley running obliquely through the hills nearly parallel to the strike of the beds. Less than a quarter of a mile northeast, but across Walnut Gap, the lowest beds exposed are assigned to the Colina limestone on the basis of lithology and contained fossils. These beds are, however, overlain by the Scherrer formation rather than the Epitaph dolomite, which overlies the Colina limestone farther south. A section of these beds is as follows:

Section of the Colina limestone

[Gunnison Hills, on Scherrer Ridge northeast of Walnut Gap (NE¼ sec. 28, T. 15 S., R. 23 E.)]

	Feet
Scherrer formation:	
Siltstone, red; forms bench.	
Colina limestone:	
1. Limestone, fine-grained; fresh fracture pink; weathered surface tan; contains silty laminations and a little chert	2½
2. Limestone, fine-grained, slightly dolomitic; fresh fracture dark gray; weathered surface light gray and rough; beds 6 to 12 in. thick	12
3. Limestone, dark-gray; mottled with pink and tan; contains small (1/16 in.) quartz nodules and also larger chert nodules	11
4. Covered except for an inch or two of marl at the base	16
5. Limestone, gray, very fine grained; beds about 6 in. thick	5
6. Limestone, dark-gray to black, fine-grained; in beds 6 in. to 3 ft thick; pink shale partings between thinner beds; scattered small nodules of chert; USSG 9406-PC contains: *Echinocrinus*, *Meekella*? cf. *M. pyramidalis* (Newberry), "*Productus*" s. l., sp. undet., *Retispira* sp. indet., pleurotomarian gastropod, new gen. and sp., *Euomphalus* sp. undet., *Orthonema*? sp	144
7. Covered except for two small ledges of light-gray to tan, fine-grained dolomitic limestone	37
8. Limestone, light- to dark-gray, fresh fracture pinkish gray; small amount of chert in top 15 ft; unit about 25 percent covered	52
9. Limestone, light-gray, dolomitic, fine-grained; unit more than 50 percent covered	48
Thickness of Colina limestone exposed	327½
Lower beds covered by alluvium.	

Although the contact of the Colina limestone with the overlying Scherrer formation is knife sharp and obviously represents a great change in conditions of deposition, no evidence of either angular or erosional unconformity was detected. The very top of the Colina is continuously exposed for long distances because of the inferior resistance of the basal siltstone of the Scherrer. The topmost beds of the Colina invariably have the distinctive lithology of units 1 and 2 of the section just given, suggesting that the contact follows the same bedding plane for about a mile, which is the total length exposed.

The concealed interval between the lower and upper parts of the Colina in the Gunnison Hills constitutes a stratigraphic problem that has not yet been thoroughly solved. In an earlier publication (Gilluly and others, 1954, p. 27), one of three hypotheses to explain the absence of the Epitaph dolomite in this area supposed that the Epitaph or its equivalent was represented in the concealed interval. This hypotheses is no longer tenable. (See below, this page.) It is possible, however, that the deposits of this interval contain a tongue of the gypsiferous strata that crop out in the Empire Mountains and other places south and southeast of Tucson (Stoyanow, 1942, p. 1275–1276; Feth, 1948, p. 90). The section immediately above the gypsiferous beds in the Empire Mountains as described by Feth and McKee (Feth, 1948, p. 97–98) is remarkably similar to the section east of Walnut Gap, a fact that has impressed Messrs. B. S. Butler, E. D. McKee, and R. M. Hernon (oral communications, 1950) who have seen both sections. Moreover, in several gullies at the north end of Walnut Gap there are small exposures of red, buff, and green shale and soft sandstone which are similar to the beds associated with the gypsum farther west (Hernon, oral communication, 1950). These exposures and several isolated outcrops of atypical limestone are shown as Colina on the geologic map. The possibility of concealed faults makes their stratigraphic position uncertain.

Thickness.—The Colina limestone in the area of this report must be more than 441 feet thick, which is the greatest thickness exposed at any one place. The actual thickness may be little or much greater depending on the interpretation of structure and stratigraphy in the concealed area. The type section of the Colina near Tombstone is 633 feet thick (Gilluly and others, 1954, p. 24). A thickness of 535 feet was measured by Sabins (1957, p. 492) in the northern Chiricahua Mountains, and a thickness of 1,000 feet is reported by R. C. Epis (written communication, 1956) in the Pedregosa Mountains.

EPITAPH DOLOMITE

The Epitaph dolomite was named by Gilluly (Gilluly and others, 1954, p. 25) in the Tombstone Hills, where it rests on the Colina limestone and is overlain unconformably by the Bisbee group of Early Cretaceous age. Although not as broadly exposed as the lower formations of the Naco group, Gilluly identified the Epitaph at many places in the Tombstone Hills and the Dragoon Mountains. In this entire area the Scherrer and Concha formations are missing and Cretaceous rocks directly overlie the Epitaph.

In the type section the Epitaph consists of about 200 feet of dolomite at the base, overlain by interbedded sandy or shaly limestone, red shale, dolomite, and calcareous sandstone, with about 100 feet of thin-bedded blue limestone at the top. The thickness, 783 feet at the type locality, varies greatly from place to place because of erosion in pre-Cretaceous time.

The basal 200 feet of dolomite, which Gilluly regarded as primary or diagenetic rather than metamorphic in origin, is the chief distinguishing member of the formation. The dolomite is gray and fine grained. It weathers with a rough "elephant-hide" surface and occurs in beds which generally do not vary much from 1 foot in thickness. A very characteristic feature is the presence of knots and small geodes of silica, which weather out on the surface. Along with these nodules are much finer granules of silica strewn parallel to the bedding. As a whole the dolomite member is resistant to erosion and forms bold outcrops and even cliffs.

The formation above the dolomite member is not very distinctive. Parts of it resemble the Earp formation in the abundance of clastic material and in features, such as beds of intraformational breccia, crossbedding, and ripple marks, that suggest shallow-water deposition. Other parts could easily be mistaken for the Colina or Horquilla limestones. A few fossils were found in the upper part—among them some *Bellerophon* specimens about the size of a tennis ball.

The only Epitaph recognized in the Dragoon quadrangle is in fault slices at the north end of the Dragoon Mountains. Several hundred feet of the basal dolomite beds are exposed and are overlain by the Glance conglomerate of Early Cretaceous age.

Recent detailed studies in several parts of southern Arizona provide data on the distribution and stratigraphic relations of the Epitaph. Near the southeastern corner of the State, in the Pedregosa Mountains, R. C. Epis (written communication, 1956) measured 1,350 feet of Epitaph overlying a thick section of Colina and underlying the Scherrer formation. In the Whetstone Mountains, southwest of Benson, W. T. Tyrell, Jr. (oral communication, 1956) has also identified Epitaph above the Colina and below the Scherrer. In the northern Chiricahua Mountains, however, the Epitaph is missing as it is in the Gunnison Hills, and the Scherrer formation lies with apparent conformity on a complete section of the Colina (Sabins, 1957, p. 494). These data establish that the Epitaph is stratigraphically between the Colina and Scherrer formations, and strongly suggest it represents a wedge, which is thickest in the southeastern corner of the State and pinches out to the northwest.

The wedge of Epitaph could be interpreted as: (1) the remnant of a once more extensive sheet, which was beveled by pre-Scherrer erosion; (2) a dolomitic facies of the upper part of the Colina; or (3) a depositional wedge, represented to the northwest by a hiatus during which neither erosion nor deposition took place. If the first interpretation is correct, some evidence of erosional unconformity at the base of the Scherrer formation would be expected. No evidence of unconformity has been reported. In the Gunnison Hills, the Colina-Scherrer contact appears to follow the same bedding plane for a mile, which is the total length exposed.

SCHERRER FORMATION

The Scherrer formation was named (Gilluly and others, 1954, p. 27) from its exposures on Scherrer Ridge of the Gunnison Hills. The base in the type locality is an easily identified plane at the bottom of a bright-red siltstone unit about 65 feet thick. The siltstone is nonresistant and forms a bench above the nearly black outcrops of the Colina limestone. Above the siltstone there are, in turn, about 30 feet of fine-grained gray limestone, 270 feet of sandstone containing a few beds of limestone in the lower part, 165 feet of gray limestone, and 150 feet of sandstone.

The sandstone is nearly white on fresh fracture but generally weathers rusty brown. It is well sorted and fine grained. The beds are 2 to 18 inches thick. A few are crossbedded and ripple marked. Exposed surfaces, at most places, are hardened to quartzite and yield much angular rubble. Thick quartzitic sandstone members like those of the Scherrer formation are not known in other formations of the Naco group.

The thick limestone member, between the two similar sandstone members, is a conspicuous feature of the formation. The limestone is fine grained, relatively thin bedded, and in part somewhat dolomitic. The prevalent color is light gray. In the lower part there are nodules or rosettes of white quartz as much as a quarter of an inch in diameter. Rusty-brown chert nodules are found sparingly throughout and are abundant in a few beds in the middle and upper part. Well-preserved echinoid spines of several obviously different types are the only fossils found. Although echinoid spines are found in other formations of the Naco group, no other formation of the area approaches the limestone of the Scherrer formation in the relative abundance, diversity of form, and perfection of preservation of this easily recognized type of fossil. (See fig. 15.)

The type section of the Scherrer formation is as follows:

Section of the Scherrer formation

[Top part measured along the crest of Concha Ridge, a transverse spur of Scherrer Ridge in the SW¼NW¼ sec. 28, T. 15 S., R. 23 E.]

	Feet
Concha limestone:	
Limestone, dark-gray, fine-grained; at bottom of saddle (unit 5, p. 69).	
Scherrer formation:	
1. Sandstone, fine-grained, quartzitic; weathers rusty brown; beds 1 to 10 in. thick; sand grains well rounded	6
2. Covered	9
3. Sandstone, like unit 1	15
4. Covered	11
5. Sandstone, like unit 1	115
6. Limestone, dark-gray, medium-grained; becomes finer grained and pink at top; very scarce chert; beds as much as 1 ft thick	11

FIGURE 15.—Echinoid spines and plates in limestone of the Scherrer formation.

Section of the Scherrer formation—Continued

	Feet
7. Limestone, light-tan to white, fine-grained; contains irregular chert nodules which weather brown	5
8. Limestone, light-gray to pink, fine-grained; contains small vugs lined with calcite crystals; beds as much as 1½ ft thick	13
9. Limestone, red, silty; beds 3 in. or less thick; partly covered	25
10. Covered	11
11. Limestone, light-gray, fine-grained; has lavender cast; contains abundant well-preserved echinoid spines and brown-weathering chert nodules	18
12. Limestone, light-gray to light-tan; contains brown-weathering chert nodules; beds as much as 1 ft thick	22
13. Limestone, light creamy gray to dark-gray, slightly dolomitic, fine-grained; weathers to pitted surface; contains scarce small (1- to 3-in.) chert nodules that weather brown; lower few feet contains small (¼-in.) nodules of white quartz; beds as much as 1 ft thick	60
Because of faults and cover in the lower part of the section at this locality, lower beds were measured about 1,750 ft to the northwest.	

Section of the Scherrer formation—Continued

[Lower part measured on west face of Scherrer Ridge in the NE¼NE¼ sec. 29, T. 15 S., R. 23 E.]

	Feet
14. Sandstone, white to rusty brown, fine-grained; in beds 2 to 12 in. thick; in places crossbedded; cementing matter slightly limy but surface commonly hardened to quartzite	148
15. Limestone, dark-gray, fine-grained, dolomitic; weathers to rough surface; lower surface of bed irregular	3
16. Sandstone, like unit 14	15
17. Limestone, gray, fine-grained; weathers to rough surface; lower surface irregular	11
18. Sandstone, like unit 14	95
19. Limestone, light-gray, fine-grained; with some pink and blue mottling, beds as much as 1 ft thick	29
20. Siltstone, red to pink, limy; in thin beds; largely covered and forms bench	65
Thickness of Scherrer formation	687

Colina limestone:
Limestone, pinkish-tan; with laminations of silt and small nodules and bands of chert (bed 2 ft thick).

The error involved in piecing together the above section is thought to be negligible because of the sharp lithologic break at the plane of correlation. Above the plane is limestone roughly 150 feet thick (units 6 to 13 inclusive); below it is sandstone roughly 270 feet thick (units 14 to 18 inclusive). Enough beds are exposed—and were measured—below the plane at the first locality and above the plane at the second locality to remove any reasonable doubt of the validity of the correlation between the two parts of the section.

Thickness.—The thickness of the Scherrer formation (687 ft) is typical of the exposures in the Gunnison Hills except where the upper part was eroded in pre-Cretaceous time, and the formation is overlain by unconformable Mesozoic rocks. Although the angular discordance between the Cretaceous and older rocks is small, the pre-Cretaceous unconformity represents a time of important faulting and deep erosion. The Glance conglomerate abruptly overlaps the older beds. Thus between the two parts of the type section of the Scherrer formation, a distance of only 1,750 feet, the Glance conglomerate fills an old valley which cuts down within several hundred feet of the bottom of the Scherrer formation. Pre-Cretaceous erosion is probably the reason the Scherrer formation is not found in the Dragoon Mountains-Tombstone area to the south. The Scherrer is 120 to 150 feet thick in the northern Chiricahua Mountains (Sabins, 1957, p. 496) and 315 feet thick in the Pedregosa Mountains (R. C. Epis, written communication, 1956). In the Empire Mountains, beds that evidently are the Scherrer formation are about 250 feet thick (Feth, 1948, p. 90).

CONCHA LIMESTONE

The Concha limestone was named (Gilluly and others, 1954, p. 29) from its outcrops on Concha Ridge, a conspicuous transverse spur of Scherrer Ridge in the Gunnison Hills.

The base of the Concha limestone was taken arbitrarily at the top of the highest rusty-weathering sandstone bed of the Scherrer formation. The lower part of the Concha consists, for the most part, of fine-grained calcareous sandstone which was assigned to the Concha rather than the Scherrer formation because it grades into the limestone above and differs from the sandstone of the Scherrer formation by being much more calcareous and gray rather than brown on weathered surfaces. It has no tendency to become silicified to quartzite on the outside but decomposes on exposure into friable rounded pebbles and cobbles. On casual inspection it might be mistaken for limestone.

Above the basal sandy beds, which are probably nowhere more than 50 feet thick, the formation consists of gray medium-grained limestone which is highly fossiliferous and contains very abundant irregular nodules of light-colored chert, which weathers pale brown. Probably the most common fossils are productid brachiopods, *Dictyoclostus ivesi bassi* (McKee), which are several inches across, 2 inches high, and substantially larger than those noted in the older formations. The top of the formation is a major unconformity above which is found either the Glance conglomerate or the Walnut Gap volcanics.

The following section, a continuation of the one on pages 68–69, is the type section of the Concha limestone:

Section of the Concha limestone

[East end of Concha Ridge (NW¼ sec. 28, T. 15 S., R. 23 E.)]

	Feet
Glance conglomerate:	
Conglomerate with limestone fragments as much as 8 in. in diameter and smaller chert fragments; fragments rounded and closely packed together but not well sorted; tightly cemented.	
Unconformity.	
Concha limestone:	
1. Limestone, gray, medium-grained; contains vary abundant irregular and rounded nodules of light-colored chert which weathers pale-brown; very fossiliferous	87
2. Limestone, light to pinkish gray, fine-grained; contains a little chert	6
3. Limestone, dark-gray, sandy; contains a little chert	4
4. Sandstone, gray, calcareous, fine-grained; sand grains angular; rock weathers into friable rounded pebbles and cobbles	31
5. Limestone, dark-gray, fine-grained; at bottom of saddle	1½
Thickness of Concha limestone	129½
Scherrer formation:	
Sandstone, fine-grained, quartzitic; weathers rusty brown (unit 1, p. 68).	

Thickness.—The thickness of the Concha limestone varies greatly within short distances because at its top is an unconformity of major importance. At several places on Scherrer Ridge, the Concha limestone is absent and the glance conglomerate rests on the Scherrer formation. The thickness measured at the type section, 129½ feet, is probably not the maximum, even on Scherrer Ridge; but the places where greater thicknesses are probably present are too much faulted and too poorly exposed for stratigraphic measurement. According to Sabins (1957, p. 497), 730 feet of Concha is preserved beneath the unconformable Glance conglomerate at one place in the Chiricahua Mountains.

AGE AND CORRELATION OF THE FORMATIONS

The age and correlation of the formation of the Naco group have been discussed in detail by James Steele Williams (Gilluly and others, 1954, p. 30–43). Available evidence indicates that lowermost Pennsylvanian (Morrow) is not represented. The Horquilla limestone ranges in age from post-Morrow Pennsylvanian to middle Late Pennsylvanian (Missouri or perhaps even Virgil) and the Earp formation from middle Late Pennsylvanian (Virgil) to lowermost Permian (Wolfcamp).[7] The Pennsylvanian-Permian boundary, as indicated by fusulinids is within the lower member of the Earp formation as it is distinguished in the Dragoon quadrangle. The Colina, Epitaph, Scherrer, and Concha formations extend the Permian record into Leonard time. The position of the Wolfcamp-Leonard boundary is uncertain because of insufficient paleontologic data; from the evidence at hand Williams (Gilluly and others, 1954, p. 41) placed it tentatively near the middle of the Colina limestone.

Correlatives of the Naco group in Arizona and New Mexico comprise many formations, largely because of facies changes that transgress time lines. The general relations are indicated if formations at the bottom and top of the group are used for reference. Concerning the Horquilla limestone Williams (Gilluly and others, 1954, p. 35) stated:

> The fauna that characterizes the lower and perhaps middle part of the Horquilla * * * is found in the middle and lower parts of the Galiuro limestone of Stoyanow in addition to being found in the Naco, of which the beds here called Horquilla were long considered to be a part. It is also present in part of the Magdalena limestone of New Mexico, and is widespread in the Rocky Mountain region in the lower Oquirrh, the Wells, Hermosa, and other formations.
>
> The presence of a form identified by Stoyanow as *Orthotichia morganiana* (Derby) suggests to him that beds of post-Des Moines Pennsylvanian or younger age are present in the upper part of the Galiuro, as indeed they are considered here to be in the upper part of the Horquilla and, of course, at some localities in some of the other formations mentioned above.

[7] The Geological Survey now classifies the Wolfcamp as Permian, instead of Permian(?) as it did when Mr. Williams' discussion was written.

The name Galiuro limestone, which was applied by Stoyanow (1926) to Pennsylvanian rocks in the Gila River basin, did not come into general use and has been abandoned by the U.S. Geological Survey. Geologists have generally used the name Naco for these rocks and for their extension northward to the pinchout beneath the Supai formation near Jerome. The Galiuro limestone and the Naco of central Arizona correlate with the Horquilla and at some places possibly with the lower part of the Earp as shown by contained fossils (Huddle and Dobrovolny, 1945). According to Huddle and Dobrovolny (1945), the Supai-Naco contact cuts down in time toward the north and west as a result of lateral gradation and interfingering, so that the lower part of the Supai is probably of Des Moines age at some places. Thus part of the Supai is thought to be equivalent to the Horquilla though much of it is younger.

Another zone of reference for correlation with formations in northern Arizona is provided by the Concha limestone which Williams (Gilluly and others, 1954, p. 43) regarded tentatively as equivalent to parts of the Snyder Hill and Chiricahua limestones of Stoyanow and to member Beta of the Kaibab, as restricted by McKee, in the Grand Canyon region. On this basis, the Earp, Colina, Epitaph, and Scherrer formations are equivalent in a general way to the middle and upper part of the Supai formation, the Hermit shale, Coconino sandstone, and the lower part of the Kaibab. Williams (Gilluly and others, 1954, p. 41) believed that the upper part of the Colina and the Epitaph are probably equivalent to the lower part of the Kaibab (possibly the Toroweap division of McKee). Sabins (1957, p. 499) did not accept this last interpretation but correlated the Coconino sandstone and the Scherrer formation.

The lower and middle part of the Magdalena group in New Mexico is in general equivalent to the Horquilla limestone, judging from published information on the group summarized by Kelley and Silver (1952, p. 88–90). In many areas, the upper part of the Magdalena and lower part of the Abo formation are probably equivalent to the Earp; but as the Abo-Magdalena contact cuts down in time toward the north, the age equivalent of the Earp is probably entirely in the limestone facies of the Magdalena in the Robledo Mountains near Las Cruces (Kelley and Silver, 1952, p. 97) and may be entirely in the Abo clastic facies farther north. Further correlations with the Permian sections in New Mexico will not be attempted.

POST-NACO–PRE-WALNUT GAP UNCONFORMITY

The top of the Naco group is everywhere defined by a major unconformity. The next younger stratified rocks generally recognized in southern Arizona belong to the Bisbee group of Early Cretaceous age. In the Dragoon quadrangle, however, volcanic rocks, here named the Walnut Gap volcanics, are intercalated locally between the Naco group and the Bisbee group. The relations indicate an unconformity beneath the Walnut Gap volcanics and another unconformity at the base of the Bisbee group. It is the older of these unconformities, preserved only beneath the Walnut Gap volcanics, that is here under consideration.

The base of the Walnut Gap volcanics is exposed near the southeast end of Walnut Gap in the Gunnison Hills, where the volcanic rocks crop out between the Naco group on the southwest and the Glance conglomerate on the northeast. The general dip of all formations is northeastward though the structure is complicated by transverse faults and small folds of post-Walnut Gap age. The surface of unconformity beneath the volcanic rocks can be located within a few feet in several of the fault blocks. At these places, there are beds of chert-sandstone conglomerate at the base of the volcanic series and a few fragments of chert and sandstone in the volcanic breccias higher in the section. Both chert and sandstone can be matched readily in the underlying formations. The basal beds rest with very slight angular discordance on the Concha limestone and the Scherrer formation. On the southwest side of the largest outcrop of the volcanic rocks, the volcanic rocks apparently truncate faults in the Naco group (pl. 2, section *O–O′*). The largest fault trends northeast and is covered by a narrow tongue of alluvium (pl. 1). This fault has a throw of approximately 450 feet and brings the Concha limestone on the southeast next to the Scherrer formation on the northwest. The base of the Walnut Gap volcanics trends northwest and truncates the concealed fault without offset. It is concluded, therefore, that the Naco group and older formations were faulted and deeply eroded before the Walnut Gap volcanics were laid down.

TRIASSIC OR JURASSIC SYSTEM

WALNUT GAP VOLCANICS

The name Walnut Gap volcanics is here given to the volcanic rocks which overlie the Naco group and underlie the Glance conglomerate east of Walnut Gap in the Gunnison Hills. The type section is on Scherrer Ridge near the southeast end of the gap.

The formation has been found at only two places in addition to the type locality. One is in a fault sliver where Highway 86 crosses Scherrer Ridge 1¼ miles northwest of the type locality. The other is 16½ miles northwest, near the quadrangle boundary 2 miles south of Kelsey Canyon. The volcanic rocks at this latter locality are overlain by the Glance conglomerate a short distance west of the quadrangle, but the relation to the underlying units is concealed by thrust faults that bring Precambrian rocks in contact with the volcanic rocks, and locally overturn them. (See pl. 2, section A–A′.)

The Walnut Gap volcanics are very easily eroded and form valleys or featureless surfaces near the local base level of erosion. Exposures are generally scarce but are conspicuous because deep red to purple characterizes most of the formation.

STRATIGRAPHY AND PETROGRAPHY

At the type locality, the formation is approximately 350 feet thick and lies unconformably on the Concha limestone and the Scherrer formation. The lowest bed is a pebble conglomerate consisting of subangular fragments of chert and sandstone, in a coarse sandy matrix. The cementing matter is ferruginous which gives the rock a bright-red color at most places. The conglomerate is locally interbedded with sandstone and andesite tuff. Above this lower part, which is probably less than 50 feet thick, the prevalent rock is fine-grained soft tuff which is mostly red but in places pale purple. Interbedded with the tuff, particularly in the central part of the mass, are andesite breccia and conglomerate containing abundant fragments of purple andesite and a few fragments of chert and sandstone. The largest fragments noted were about 6 inches in diameter. These beds are commonly 6 to 12 inches thick and evidently water laid. No lava flows have been identified, but some decomposed flows may have been overlooked among the fine-grained soft tuffs, in which the clastic texture is generally obscure.

The top of the Walnut Gap volcanics is a clear-cut unconformity at the base of the Glance conglomerate (fig. 16). The Walnut Gap-Glance contact is knife sharp, and there is no evidence of interfingering. We did not find unequivocal volcanic debris anywhere in the Glance. At the locality pictured, the basal part of the conglomerate has a ferruginous matrix and contains scarce small chloritized fragments probably derived from volcanic rock. We believe some of the matrix material and the chloritic fragments represent debris eroded from the underlying volcanic rocks. The lack of positively identifiable volcanic detritus is attributed to the altered decomposed condition of the local volcanic outcrops. Volcanic detritus reported in the Bisbee in other areas (Gilluly, 1956, p. 79–80) may have come from a less altered facies of the Walnut Gap formation.

The spatial relations of the Walnut Gap and Glance formations indicate that the post-Walnut Gap unconformity represents a period of structural disturbance and deep erosion, suggesting that it represents a considerable time interval. The Walnut Gap volcanics

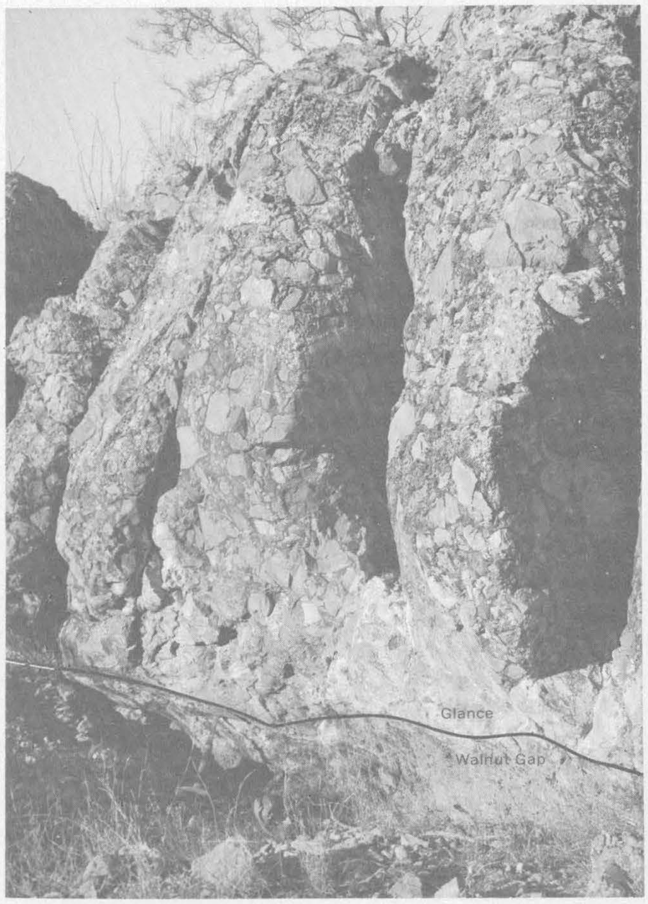

FIGURE 16.—Glance conglomerate resting on Walnut Gap volcanics near the south end of Walnut Gap. Geologic pick marks contact.

were completely eroded at most places. Between the two remnants of Walnut Gap in the Gunnison Hills, the Glance fills a deep post-Walnut Gap valley in formation of the Naco group (pl. 1).

The andesite consists of phenocrysts of plagioclase and altered hornblende in an aphanitic purple groundmass. The largest phenocrysts are about 5 mm long, but most of them are much smaller. The plagioclase phenocrysts are albite (An_{5-10}), which contains calcite and a nearly isotropic clay mineral. The original hornblende phenocrysts have been completely altered and are represented by pseudomorphs having a rim of iron oxides, which faithfully preserve the shape of the original crystal, and a core made up of variable proportions of iron oxides, quartz, calcite, chlorite, and epidote. The groundmass is very largely albite, some of which has the form of distinct microlites. Dusty inclusions give the rock its purple color. The groundmass here and there has been replaced by calcite and granular quartz. Apatite and magnetite are conspicuous accessory minerals. Associated with the andesite are a few fragments of dacite, a rock similar to the andesite but with phenocrysts of quartz.

We regard the volcanic rocks at the other two localities as part of the same formation because of lithologic similarities and identical relation to the overlying Glance conglomerate. At the locality near Highway 86, the volcanic rocks are richer in quartz and contained biotite as a primary mineral. They consist in part of soft brick-red tuff(?) which contains grains of quartz a millimeter or two in diameter. In thin section the rock is seen to be largely sericite, which includes angular fragments of quartz, fine-grained felsitic quartz aggregates, sericitized biotite, and sericite-rich aggregates which probably represent feldspar. Microveinlets and disseminations of iron oxide are responsible for the red color. There are also outcrops of gray-green pyroclastic breccia composed largely of dacite fragments. The dacite has phenocrysts of quartz and albite, 1 to 4 mm in diameter, in an aphanitic groundmass. The albite contains much chlorite and a little sericite. The quartz phenocrysts are corroded and embayed by the groundmass. There are also pseudomorphs of sericite, chlorite, and iron oxides, after thick books of biotite. The groundmass is a fine-grained aggregate consisting largely of chlorite and quartz.

South of Kelsey Canyon, the exposed thickness of the formation is at least 500 feet and may be as much as 1,000 feet; the base is not exposed. The formation here consists of poorly bedded and unbedded pyroclastic rocks, ranging from fine-grained tuffs to breccias, which contain fragments as much as a foot in diameter. The fragments are generally angular lithic clasts consisting of variable proportions of altered plagioclase, hornblende(?), and rare quartz phenocrysts as much as 3 or 4 mm in diameter in a red-brown to purple aphanitic groundmass. The matrix in which the fragments are embedded is typically bright red brown or magenta because of pervasive hematite. The plagioclase is largely but not completely albitized and contains some calcite and clay minerals. The former ferromagnesian minerals have been replaced by iron oxide dust, silica, clay minerals, and traces of chlorite. These aggregates generally have a conspicuous corona of magnetite dust. Intercalated with the breccias, at a few places, are rounded pebble and cobble conglomerate beds. The fragments are of volcanic rock and locally of limestone and chert.

AGE AND CORRELATION

The geologic relations show that the Walnut Gap volcanics are younger than the Naco group and hence are post-Permian in age. The unconformable relation of the overlying Glance conglomerate indicates that the Walnut Gap volcanics is pre-Early Cretaceous. Lacking evidence for more precise dating we regard the formation as either Triassic or Jurassic in age.

A volcanic formation of this age, though not previously reported in Arizona, fits in well with what is known of the geology of the State. As shown by Waters and Granger (1953), the Shinarump conglomerate and Chinle formation (Triassic) and the Morrison formation (Jurassic) of northeastern Arizona and adjacent States contain much volcanic debris of a type indicating contemporaneous volcanic activity. The data (Waters and Granger, 1953, p. 6, 8) suggest that the southerly exposures of the Shinarump (Fort Defiance, Ariz.) and Chinle (Petrified Forest National Monument) contain the best preserved and coarsest volcanic debris and fragments of pumice and other volcanic rocks as large as 1 cm in size. Moreover, Longwell (1928, p. 56), Allen (1930, p. 288), and others think the Shinarump and Chinle sequence had its source in highlands to the south and southeast. Detailed stratigraphic studies by the Geological Survey (Craig and others, 1955, p. 150) indicate two principal source areas for the Morrison formation, one probably in west-central Arizona and the other south of Gallup, N. Mex.

The Walnut Gap volcanics could represent volcanic eruptions in the same igneous cycle that gave rise to the Juniper Flat granite in the Mule Mountains near Bisbee. Gilluly (1956, p. 55) found that this granite intruded the Naco group and is overlain unconformably by the Glance; he classified it as Triassic or Jurassic in age. The Walnut Gap volcanics could also have provided the volcanic fragments reported (Gilluly, 1956, p. 79–80; Jones and Cushman, 1947, p. 7) in the Bisbee group.

POST-WALNUT GAP-PRE-BISBEE UNCONFORMITY

In the Dragoon quadrangle, the Bisbee group lies unconformably on the Walnut Gap volcanics, the Concha limestone, Scherrer formation, and, if our identification of the Glance conglomerate in Kelsey Canyon is correct, on the Horquilla limestone. There is little angular discordance. In the Gunnison Hills, the Glance lies on a deeply channeled surface that truncates some of the faults in the Paleozoic rocks (pl. 1). Evidently, before the Bisbee group was deposited, the Paleozoic rocks were faulted (though apparently not folded), uplifted, and deeply eroded.

Some of the pre-Bisbee deformation of the Paleozoic rocks was older than the Walnut Gap volcanics, but some of it was younger than that formation. The Walnut Gap in the Gunnison Hills is preserved in fault blocks that were dropped down before the Glance conglomerate was deposited. Post-Glance movement on the bounding faults has obscured but not obliterated this relation (pl. 1). The structural relief caused by the two deformations was probably not very great in the Dragoon quadrangle, for neither the Walnut Gap nor the Glance is found in depositional contact on rocks older than the Naco group.

Pre-Bisbee erosion at most places removed the Walnut Gap volcanics and a considerable part of the Naco group, but it did not result in a peneplained surface. There must have been highlands nearby to yield the thick layer of coarse detritus that makes up the Glance conglomerate. The Glance, in the Gunnison Hills, filled an old valley about a mile wide and 500 feet deep cut in the Concha limestone and the Scherrer formation (pl. 1).

CRETACEOUS SYSTEM

BISBEE GROUP

Dumble (1902, p. 706) gave the name Bisbee beds to a thick section of clastic and carbonate strata of Cretaceous age near Bisbee. Ransome (1904, p. 56) used the name Bisbee group for the same beds and distinguished four formations: the Glance conglomerate (0–500 ft) at the base, the Morita formation (1,800 ft), the Mural limestone (650 ft), and the Cintura formation (1,800 ft). Gilluly (1956, p. 74) found that the Mural limestone wedges out rapidly toward the north. It has not been recognized north of the Mule Mountains, and, in its absence, it is not feasible to separate the Morita and Cintura formations, which are much alike lithologically. Therefore Gilluly has used a single map unit, the Bisbee formation, in the Dragoon Mountains area. He recognized the Glance conglomerate as the basal member of this formation, and believed the upper part represents the Morita formation, Cintura formation, and perhaps beds younger than any of those preserved at Bisbee. We follow Gilluly's interpretation but retain the name Bisbee group to include two map units, the Glance conglomerate and the Morita and Cintura formations, undivided.

GLANCE CONGLOMERATE

The Glance conglomerate makes up the north end of the Gunnison Hills and extends down the east side of these hills as an unconformable overlapping blanket on the Walnut Gap volcanics, Concha limestone, and Scherrer formation. It also occurs in the thrust zone at the north end of the Dragoon Mountains where it rests on the Epitaph dolomite. The rock mapped in Kelsey Canyon as Glance(?) has certain lithologic peculiarities that suggest it could represent a lower member of the Threelinks conglomerate. About 2 miles southwest of the Kelsey Canyon locality and just outside the Dragoon quadrangle, Glance of the usual type crops out next to the patch of Walnut Gap volcanics that shows on the map (pl. 1).

The Glance conglomerate is a massive formation, more resistant to erosion than the Walnut Gap volcanics but less resistant than the formations of the Naco group. It generally forms smooth featureless surfaces and is commonly found at the foot of dip slopes. In the Gunnison Hills area, the surface on the Glance is much like that cut on alluvium but supports a fairly thick growth of ocotillo not found on the adjacent alluvium.

LITHOLOGY

In the Gunnison Hills area, the conglomerate is remarkably uniform, consisting of angular and subangular fragments of Paleozoic sedimentary rocks, mostly limestone from the Naco group. Fragments of all sizes up to about a foot in diameter are closely packed together in a sandy matrix which is tightly cemented by calcite (fig. 16). The rock breaks through the fragments as easily as around them. Sorting is poor and bedding is inconspicuous. A few thin interbeds of buff calcareous sandstone and red shale occur in the highest part exposed.

The conglomerate in the exposures at the north end of the Dragoon Mountains is finer grained than in the Gunnison Hills and has a higher proportion of interbedded sandstone and shale. The sandstone is green to purple and commonly somewhat shaly. The shale is hard, greenish to purplish gray, and commonly has pebbles scattered through it.

The Glance(?) in Kelsey Canyon resembles that in the Gunnison Hills in general composition and texture but is finer grained on the average, more distinctly bedded, and less well cemented. The possibility that the rock is a lower member of the Threelinks conglomerate is discussed in connection with that formation.

THICKNESS AND ORIGIN

As no sections showing both top and bottom of the conglomerate were found, the thickness is not known. It must be hundreds of feet thick and an apparent thickness of at least 1,000 feet is present in the Red Bird Hills, a few miles east of the area mapped.

The regional relations indicate rapid southward variation in thickness and lithology. At the north end of the Dragoon Mountains, the conglomerate is finer than to the north and contains more interbedded sandstone and shale. Still farther south in the range, limestone conglomerate units, locally as much as several scores of feet in thickness, are reported (Gilluly, 1956, p. 77) near the base of the Bisbee formation. The spatial relations suggest interfingering and hence that the conglomerate is in part the age equivalent of finer clastic sediments to the south. A factor affecting the thickness of the conglomerate is the irregular surface on which it was deposited, as pointed out by many geologists (Ransome, 1904, p. 57; Gilluly, 1956, p. 71). An excellent, though relatively small scale, example of this effect is found in the Gunnison Hills a mile southeast of Highway 86 where the thickness is increased several hundred feet as a result of the filling of a pre-Glance valley.

It is hard to imagine how such a thick coarse generally ill sorted conglomerate was deposited. In the type area, Ransome (1904, p. 62) interpreted it as a "coarse littoral deposit laid down along a marine shoreline that rapidly encroached upon the land as a consequence of the latter's subsidence." This would explain the local derivation and size variation of the boulders, and, perhaps, the lack of sorting but can hardly explain the great thickness. It seems more probable that it is largely a terrestrial deposit, perhaps a series of partly confluent fanglomerates. Any interpretation requires contemporaneous highlands in the vicinity to provide so much coarse clastic material. The preponderance of limestone boulders indicates a condition in which mechanical weathering exceeded chemical decomposition and suggests an arid climate.

MORITA AND CINTURA FORMATIONS UNDIVIDED

The Morita and Cintura formations are exposed in a belt about 4 miles long and a mile wide northeast of the Steele Hills and are also exposed in a smaller area near Antelope Tank at the south end of these hills. The formations also crop out in the southern part of the Little Dragoon Mountains next to the Texas Canyon quartz monzonite and as roof pendants in the quartz monzonite and aplite. They are not known elsewhere in the Dragoon quadrangle but have been identified doubtfully a few hundred feet west of the quadrangle boundary near the American mine beneath thrust plates of Naco group limestone.

At the localities near the Steele Hills and American mine, the formations are relatively nonresistant to erosion and have been reduced to the pediment level. Contact metamorphism at the localities in the Little Dragoon Mountains has made the formations resistant, and they form part of Adams Peak and several conspicuous brown hills between Texas Canyon and Dragoon.

The Morita and Cintura formations undivided were not found in contact with the Glance conglomerate within the Dragoon quadrangle. Near Antelope Tank the Glance dips to the north toward the Morita and Cintura formations which crop out a quarter of a mile away and dip in the same general direction. If there were no structural complications there would be room for about a thousand feet of beds in the concealed interval; but the structure of the Galiuro volcanics and Threelinks conglomerate indicates that the alluvium immediately north of the Glance outcrops conceals a fault trending west-northwest, and that the north side was downthrown at least several hundred feet in late Tertiary time. This fault was probably active in pre-Tertiary time also (p. 113–114), and the section faulted out may be very thick.

The Morita and Cintura strata exposed near Antelope Tank consist of soft yellow siltstone interbedded wiuh yellowish-brown fine-grained sandstone and laminated limestone. The sandstone and limestone units are rarely as much as 5 feet thick. The limestone is present in relatively small quantities but is very distinctive. It is generally a fine-grained flaggy rock. The weathered surface shows alternate bands of medium-gray limestone and light-gray to tan silty limestone. There are commonly 15 to 20 distinct color bands to the inch. Most of the bands are themselves made up of paper-thin laminae. Some of the limestone and sandstone strata contain minute black filaments which seem to be the carbonized residue of rootlets or twigs. Some layers have angular cavities, as much as half an inch in length, that appear to be molds of gypsum or tabular salt crystals.

In the pediment east of the Steele Hills, the Morita and Cintura formations are different lithologically from the exposures near Antelope Tank. They consist of light-colored quartzite interbedded with purplish-red shale and siltstone. There are scarce thin beds of round-pebble quartz and chert conglomerate and at least one 15-foot bed of coarse limestone conglomerate which resembles the Glance. A few limestone beds less than a foot thick were observed. These are brownish gray, unlaminated, and very silty. The quartzite beds are conspicuous and generally distinctive. They are commonly crossbedded and at many places contain small round chert pebbles, some of them coal black. Most of the quartzite beds contain very little other than quartz; others contain much detrital feldspar; a few also contain a considerable quantity of ferromagnesian minerals. The last-mentioned layers resemble many beds in the undifferentiated Cretaceous(?) rocks that crop out a few miles to the northeast. The beds in the Morita and Cintura east of the Steele Hills here and there contain fragments of silicified wood. The largest fragment seen was a log about 2 feet in diameter. None of the wood appears to be in the position of growth.

The Morita and Cintura rocks in the southwestern part of the Little Dragoon Mountains were probably similar originally to those on the east side of the Steele Hills. The quartzite is thoroughly recrystallized; the argillaceous beds have been converted to quartz-mica, chiastolite-mica, and sillimanite-mica schists; and the calcareous rocks are represented by lime-silicate hornfels. The chiastolite and sillimanite are characteristically in porphyroblasts ½ to 1½ inches long, but the other constituents are fine to medium grained. Bedding is generally well perserved but primary depositional details like crossbedding were not found. The recrystallization and reconstitution, which were evidently a contact effect of the Texas Canyon quartz monzonite, appear to have been preceded by pervasive shearing, for relict foliation is evident in all the rock types except pure quartzite and lime-silicate hornsfels.

Foliation is most conspicuous near the Laramide thrust fault that forms the northeastern contact of the formations west of Dragoon. Most of the rock in this zone is an augen gneiss, with foliation dipping 26° to 60° SW. The augen are elliptical masses of quartz as much as 2 inches long; some of these clearly represent original pebbles. The texture of the gneiss in thin section is thoroughly metamorphic. Eyes of recrystallized quartz occur in a groundmass of finer grained quartz, alkalic feldspar, muscovite, biotite, epidote, and dark-green amphibole. The foliation is due to the orientation of the quartz eyes and concentration of other minerals in flat lenses and streaks. Some of the amphibole is in large poikiloblastic crystals at all angles to the foliation. According to our interpretation, the rock was thoroughly sheared at the time of the thrusting and later was hornfelsed by the quartz monzonite.

An unusual conglomerate, which may represent a less metamorphosed facies of the unit just described, is exposed in a window in the alluvium in the northern part of sec. 26, T. 16 S., R. 22 E. This rock consists of fragments of Pinal schist, quartzite, vein quartz, and granitic igneous rock in a schist matrix. The bedding and schistosity of the Pinal fragments lie at all angles to the later foliation of the matrix.

In many respects the metamorphosed facies of the Morita and Cintura formations resemble the Pinal schist. They may be distinguished from the Pinal by the presence of abundant and nearly pure quartzite, beds of lime-silicate hornfels, and, of course, by conglomerate carrying Pinal schist fragments.

Thickness.—Only partial sections of the Morita and Cintura formations are exposed in the Dragoon quadrangle, and no stratigraphic measurements were made. The dip and outcrop width indicate 2,500 feet of beds in the roof pendant east of Adams Ranch and about the same thickness northeast of the Gunnison Hills. Near Antelope Tank a few hundred feet of beds are repeated by isoclinal folds. No marker beds were found to permit piecing the partial sections together. The total thickness of the formations may be many thousands of feet, as geologic mapping (Gilluly, 1956, p. 78) about 12 miles southeast of the Dragoon quadrangle in the vicinity of Walnut Springs has shown some 15,000 feet of beds without either top or bottom exposed.

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AGE AND CORRELATION

The rocks here assigned to the Bisbee group are younger than the Walnut Gap volcanics and older than the folding and overthrusting that took place in Late Cretaceous or early Tertiary time. The only fossils found in the rocks in the Dragoon quadrangle are silicified wood, in the outcrops northeast of the Steele Hills. Specimens of this wood have been examined by R. W. Brown of the Geological Survey, who stated (written communication, 1950), "This is coniferous wood and very likely a species of *Cupressinoxylon*. As no thorough studies of these woods have been made, the identification of species is not reliable." *Cupressinoxylon* is a Cretaceous genus found in both Lower and Upper Cretaceous beds.

The rocks were assigned to the Bisbee group of Early Cretaceous (Comanche) age because of lithology and general geological relations. The lithology is similar to parts of the type section of the group at Bisbee and even more similar to the Bisbee formation which Gilluly mapped to the south edge of the Dragoon quadrangle. The relation of the rocks to the Naco group and to the folding and overthrusting is the same.

A gradual change in facies toward the north may explain the relative scarcity of fossils in the Dragoon quadrangle. Stoyanow (1949) described a rich ammonite fauna from the Bisbee area. Fossil collections from the area between Bisbee and the Dragoon quadrangle have been studied by J. B. Reeside, Jr. (Gilluly, 1956, p. 83) who found a pelecypod-gastropod facies almost totally lacking in ammonites, and he suggested that this assemblage might represent habitats nearer shore than those of the ammonite-bearing facies. Gilluly (1956, p. 78–79) believed the formation was deposited in an estuary because of the lithology, the presence of beds containing fresh-water fossils as far south as Tombstone, and the presence of beds with marine fossils as far north as the foothills east of Black Diamond Peak in the Dragoon Mountains. Only land plants were found in the Dragoon quadrangle. There appears to have been a change in the environment of deposition, from open marine conditions along the international boundary, through estuarine conditions, to largely terrestrial conditions in the Dragoon quadrangle.

The age of the fossiliferous beds in the type area is well established. Fossils collected by Ransome, chiefly from the Mural limestone, were studied by T. W. Stanton who stated (Ransome, 1904, p. 70),

> It is safe to conclude that the fossiliferous horizon represented by these collections corresponds in large part with the Glen Rose beds of Texas, and that possibly the upper portion is as high as the Edwards limestone; in other words, that they certainly belong to the Trinity division and possibly in part to the Fredericksburg division of the Comanche series.

Subsequent detailed studies by Stoyanow (1949) have permitted zonation of the fossiliferous units on the basis of ammonites and indicated that both Aptian and Albion stages are represented. Stratigraphically below correlatives of the Travis Peak, Cuchillo (Burrows, 1909), and Glen Rose formations of Texas are beds which contain fossils which are not reported elsewhere in North America and which he believed are older than any paleontologically characterized Aptian stratigraphic unit in Texas (Stoyanow, 1949, p. 39–40). J. B. Reeside's studies (Gilluly, 1956, p. 83) suggest little difference in age between the Arizona horizons represented in collections from central Cochise County and the Trinity group of Arkansas and Texas.

CRETACEOUS(?) SYSTEM

CLASTIC SEDIMENTARY AND VOLCANIC ROCKS OF THE WINCHESTER MOUNTAINS

Clastic sedimentary and volcanic rocks, presumed to be of Cretaceous age, are exposed here and there within an area of several square miles at the foot of the Winchester Mountains in the northeast corner of the Dragoon quadrangle. These rocks are less resistant than adjacent formations and, as a result, crop out on the lower slopes and along recently incised stream channels in the valley floor.

STRATIGRAPHY

As the rocks are nonfossiliferous so far as known and are everywhere bounded by faults or Quaternary alluvium and landslides, the stratigraphic relations must be inferred from indirect evidence. The rocks strike northwest nearly parallel to the strike of the Morita and Cintura formations farther south and dip southwest at angles up to the vertical. Crossbedding and channeling, observed at a few widely separated localities, indicate the beds face southwest and are thus upright rather than overturned. The stratigraphically lowest beds are in fault contact with linestone of upper Paleozoic age in the NE¼ sec. 5, T. 14 S., R. 23 E.; and, a short distance north of the quadrangle boundary, with granite of Precambrian age. A fault slice of Glance conglomerate, too small to be mapped on the scale of plate 1, occurs along the fault line at one place.

The formation is divisible into two members. The lower member is exposed in a belt about three-quarters of a mile wide parallel to the strike and adjacent to the bounding fault and consists of feldspathic sandstone, siltstone, conglomerate, and a few small lenses of rhyolitic tuff and flow breccia. The sandstone, which is much the most conspicuous lithologic type, is well indurated and is generally greenish gray on fresh fracture and olive brown on weathered surfaces. The grains are subangular and range in size from fine sand to grit about 1/10 inch in diameter. Quartz and feldspar are the principal constituents and are present in roughly equal proportion. About 5 percent of biotite and other ferromagnesian constituents is characteristic. Rounded pebbles and boulders are scattered through some of the beds. Individual sandstone units range from 6 inches to as much as 20 feet in thickness and alternate with pale reddish-brown to purple siltstone or conglomerate.

At three localities outcrops of rhyolitic rock were observed. None of the exposures could be traced as much as 100 feet in any direction. The rock consists of phenocrysts of feldspar, mica, and scarce quartz in a light-gray aphanitic groundmass. These rocks are regarded as small lenses of lithic tuff and flow breccia. The tuffs are characterized by fragmental textures and the flow breccias by scattered angular fragments in a groundmass having essentially the same composition and texture as the fragments. All outcrops observed are much decomposed, apparently as a result of weathering.

The conglomerate in the lower member contains fragments of diverse rock types, including quartzite, limestone, feldspathic sandstone, rhyolite, andesite, granite, and limestone conglomerate that is like the Glance conglomerate. The conglomerate in the lower part is characterized by well-rounded pebbles 1 to 3 inches in diameter in a matrix that is indistinguishable from nearby sandstone beds. Poorly sorted conglomerate with boulders as much as 2 feet in diameter occur higher in the section.

Between three-quarters of a mile and a mile southwest of the bounding fault with the Paleozoic rocks, a gradual change in lithology takes place. Beds of purple and reddish-brown andesite tuff and tuff-breccia appear, and pebbles of quartzite and limestone become less abundant in the conglomerate. Above the transition zone there are tuffs, breccias, scarce volcanic conglomerate, and at least one lava flow. Tuff and tuff-breccia are the most common rock types. These rocks are less distinctly stratified than those of the lower member and are dark purple or red brown rather than green.

The upper volcanic member resembles the Walnut Gap volcanics and would be very difficult to distinguish from that formation in isolated outcrops. It is assigned to this formation because it grades downward into a thick sedimentary member that has no counterpart in the Walnut Gap and particularly because the lower sedimentary member contains pebbles and boulders of limestone conglomerate unlike any known beds stratgraphically below the Glance conglomerate. The Glance is clearly younger than the Walnut Gap as previously noted.

The typical andesite in the upper member contains about 40 percent phenocrysts of plagioclase a millimeter or two in length and 5 to 10 percent phenocrysts of ferromagnesian minerals about the same size; these phenocrysts are in an aphanitic purple or maroon groundmass. Under the microscope less alteration is apparent than in the Walnut Gap volcanics. The plagioclase phenocrysts are andesine, generally An_{45} but as low as An_{35} in some specimens. The andesine shows slight progressive and oscillatory zoning and is partly albitized around the margins and along cracks. The ferromagnesian phenocrysts are hornblende and thick books of biotite, in roughly equal proportion in the best preserved specimen studied. The ferromagnesian minerals are generally more altered than the plagioclase and in some specimens are represented by iron oxides and other secondary products. Identifiable quartz is wholly absent in most of the thin sections examined but in one section constitutes about 8 percent and occurs mostly if not wholly as fillings of minute cavities, some of which have a central core of calcite. The quartz shows growth lines subparallel to the cavity walls and the shape of these lines suggests minute tridymite crystals that the quartz has replaced. Magnetite and apatite are abundant accessory minerals, and a few small zircon crystals are present. The groundmass is holocrystalline but too fine grained for mineral identification.

Most of the tuff has the texture of medium- to coarse-grained sandstone and is composed largely of fragments of the phenocrysts from the andesite. Minute fragments of the andesite are common, but no shards or pumice fragments have been detected. Blocks of andesite are scattered through the tuff and in places are so abundant that the rock is a true volcanic breccia.

Volcanic formations in the area, other than the Walnut Gap volcanics, are not likely to be mistaken for the andesite here under consideration. The andesite flow in the Threelinks conglomerate lacks phenocrysts of feldspar and contains abundant augite which is lacking in these rocks. The andesite in the Galiuro volcanics (and a similar basalt in the Threelinks conglomerate) contains unusually large plagioclase phenocrysts, pyroxene phenocrysts, and dark-gray or brown groundmass. The other members of the Galiuro volcanics are all lighter colored fresher more siliceous rocks.

Thickness.—No detailed stratigraphic measurements were made but calculations based on the dip and outcrop width suggest that the exposed thickness of the lower, predominantly sedimentary, member is about 4,000 feet and of the upper andesitic member 950 feet. There may be repetition by faulting as there are concealed intervals, and distinctive marker beds are lacking.

AGE AND CORRELATION

The rocks here under consideration are thought to be younger than the Bisbee group because they contain fragments of the Glance conglomerate. The steep dips, structural trend, and fault relations suggest that they are older than the major thrust faults. (See pl. 2, section *I–I′*.) The rocks are regarded, therefore, as most probably of late Early or Late Cretaceous age. It is possible, of course, that they are early Tertiary rather than Cretaceous.

Volcanic rocks of both Early and Late Cretaceous age have been reported from the general region. In the Little Hatchet Mountains of southwestern New Mexico, andesitic breccias are interbedded with limestones of Early Cretaceous age (Lasky, 1947, p. 20–21). Thus there is a possible correlative among the Lower Cretaceous rocks of the region. There is also a possible correlative among the Upper Cretaceous rocks. In the Stanley district about 60 miles northwest of the Winchester Mountains locality, lavas and volcanic breccias, principally andesitic in composition, are interbedded with fossiliferous Upper Cretaceous sedimentary rocks according to Ross (1925, p. 25). Similar andesitic breccias are found above the Colorado shale in the Silver City region of New Mexico (Paige, 1916, p. 7). Upper Cretaceous sedimentary rocks with intercalated rhyolitic tuff have been described (Taliaferro, 1933, p. 25) in the Cabullona basin in the Province of Sonora, 25 miles southwest of Douglas, Ariz.

TERTIARY(?) SYSTEM

TEXAS CANYON QUARTZ MONZONITE

The granitic rock that forms much of the southeastern half of the Little Dragoon Mountains is here named the Texas Canyon quartz monzonite from its excellent exposures in Texas Canyon through which Highway 86 passes. The area of outcrop is roughly 4 by 6½ miles; the long axis trends northeast. The full size of the body is larger than this, for parts of the eastern and southern boundaries are made by overlapping alluvium. As there is some reason to believe the concealed intrusive contacts are not far out beneath the alluvial cover, the body will be referred to as a stock though it could expand to batholitic proportions beneath the alluvium of the San Pedro valley.

The quartz monzonite weathers fairly rapidly to arkosic sand. The weathering takes place both at the exposed surface and along joints and results in outcrops that have smooth rounded forms. Spectacular pedestal rocks and balanced boulders are common. The typical topography consists of such outcrops separated by swales of sand containing sporadic cobbles of aplite and vein quartz. Conspicuous rocky ridges and monolithic peaks occur along the main drainage divides and where joints are wide spaced, but these eminences are of moderate height and on the whole the quartz monzonite has been eroded to lower elevations than the rocks it has invaded. The altered parts of the quartz monzonite and associated quartz veins generally form low ridges that lack the smooth rounded outcrops characteristic of the unaltered rock.

GEOLOGIC RELATIONS

For about 4½ miles along the northwestern side of the stock, the quartz monzonite has invaded the Pinal schist and has a steep arcuate contact that tends to be concordant with the bedding and foliation in the schist. This relatively smooth part of the contact ends where the quartz monzonite has intruded the younger rocks. About a mile southwest of Johnson, where the quartz monzonite has intruded the Apache group, the contact turns abruptly to the southeast and becomes discordant and irregular. At the lower end of Sheep Basin the quartz monzonite has invaded thrust sheets of Paleozoic and Cretaceous rocks, and the contact swings toward the south; large masses of aplite have been intruded along this part of the contact. Much of the intrusive contact on the east and south is concealed by overlapping alluvium, but parts are exposed northeast of Lancha. In these parts the quartz monzonite cuts folded and thrust-faulted rocks ranging from the Pinal schist to the Morita and Cintura formations, and the contact is discordant and irregular.

The contact relations at the south end of the mass strongly suggest a gently arched irregular roof which has not been completely removed by erosion. Southwest of Dragoon the trace of the main intrusive contact on the topography indicates an inclination of 15° or less to the east. The quartz monzonite and associated aplite to the west contain large inclusions that evidently represent roof pendants, for they are most common on hilltops and their internal structure conforms to that in the walls.

East of Texas Canyon Wash and south of the largest roof pendant, the quartz monzonite contains numerous small inclusions of schist and is commonly sheared and locally even gneissic. At the few places where the attitude could be determined, the dip of the foliation is about 20° in diverse directions. The normal unsheared quartz monzonite grades into the sheared and inclusion-bearing facies, which is regarded as a protoclastic border phase indicating that the roof was not far above. The time of shearing as fixed by aplite dikes suggests a protoclastic origin. Some aplite dikes are older and some younger than the shearing.

The relations suggest that the stock has steep generally concordant walls in the Pinal schist and a discordant generally flat roof where it cuts up into the post-Pinal rocks. It is only along the northwest side that erosion has cut deep enough to expose the steep wall, but the contact of the quartz monzonite and Pinal schist exposed near the Centurion mine and the Standard prospect tends to be concordant and may represent another steep wall trending north to north-northeast. Evidence suggesting a gently arched roof is pointed out above. A northeastward extension of this roof, at moderate depth, is suggested by intense igneous metamorphism near Johnson, as much as 1½ miles from the exposed contact, and by the occurrence of metamorphic tremolite in the Glance conglomerate at the north end of the Gunnison Hills, as much as 3 miles from exposed quartz monzonite. No quartz monzonite, however, has been found yet in mine workings or borings near Johnson.

At a few places around the stock there is evidence of forceful intrusion. South of Johnson, for example, the Apache group is complexly folded and schistose for 500 to 1,500 feet from its contact with the stock. An eastward-plunging anticline with limbs dipping about 40° causes the outcrop of the Scanlan conglomerate and Pioneer shale to swing in the shape of a U that is open to the west (pls. 1, 6). The diabase sills, Barnes conglomerate, and Dripping Spring quartzite are exposed in normal position on the south limb of the fold in an embayment in the stock. The Scanlan conglomerate and Pioneer shale are crumpled near the axis of the anticline; and, though the anticline cannot be traced far to the east, the zone of crumpling continues in that direction and curves southward through an arc of 75° subparallel to the intrusive contact. The curved zone is about half a mile long, and at both ends the schistosity in the underlying Pinal schist strikes subparallel to the folds in the Apache group. No indication of the anticline and associated crumpling, or of similar structural features, is seen in the post-Pinal rocks of Johnson Peak to the west or in the Johnson Camp mining area to the north and east. In the latter area a northeastward-dipping homocline is modified only by very gentle flexures trending north and by faults. The close folding and local change in trend of schistosity in the basement are attributed to lateral shouldering action by the stock because the structural features are unlike others in the vicinity, and they are parallel to the intrusive contact and are confined to a small arcuate area next to the stock. The quartz monzonite is not sheared in this vicinity, and unsheared dikes and apophyses of quartz monzonite and aplite cut the folds.

The facts suggest two stages of emplacement: an early stage of forceful injection and a later quiet stage of stoping. The evidence for forceful injection includes the minor folding south of Johnson, the shearing of the quartz monzonite near the roof in the southernmost exposures of the stock, and the tendency for the schistosity of the Pinal schist to parallel the contacts of the stock. In the faulted syncline on the north side of Sheep Basin, northeastward-trending schistosity and cleavage have been developed in the Pioneer shale and diabase near the stock. These shearing effects are probably due to lateral pressure from the stock rather than earlier deformation for they parallel the intrusive contact rather than the fold axis. The evidence for stoping during the later quiet stage is of the negative kind and consists of the lack of primary flow structure and protoclastic borders in most parts of the stock, and the scarcity of places where the walls give evidence of having been shouldered aside. It is imagined that the deformed zones near the initial contacts have been stoped out except locally.

Brief reconnaissance near Johnson led Kellogg (1906, p. 652) to postulate that forceful intrusion of the stock had tilted the beds there; but our regional mapping shows that most, perhaps all, of the tilting is of earlier origin. The tilted rocks extend with a sinuous course across the northeastern part of the Little Dragoons and appear again on the opposite side of Tres Alamos Wash, whence they continue northwestward to Kelsey Canyon. The tilting is evidently part of the major regional structure and not of local origin. Remnants of a thrust plate that rests on the tilted block between Lime and Johnson Peaks indicate the folding was earlier than the thrusting, which in turn was earlier than the quartz monzonite intrusion. The only facts that imply doming by the intrusion are found in the southern part of the stock, where roof pendants of the Morita and Cintura formations are found high on Adams Peak. As this formation underlies virtually flat thrust sheets of Paleozoic rocks at considerably lower elevations a short distance to the west, some doming by the intrusion is suggested.

Steep joints that strike northeast are conspicuous throughout the Texas Canyon stock. Other sets of steep joints are well developed locally. The overall pattern based on 1,658 measurements well scattered over the stock is given in figure 17. This diagram shows that the preponderance of joints reach a maximum near N. 45° E., 86° SE. Most of the other joints fall in a girdle with poorly defined maxima near N. 5° W., 65° W. and N. 75° W., 85° S. The predominant set is chiefly parallel to the long axis of the intrusive body as exposed, but the relation of these joints and others to the flowage direction of the magma is not known because of the obscurity of flow structures. The joints formed before intrusion of the Tertiary(?)

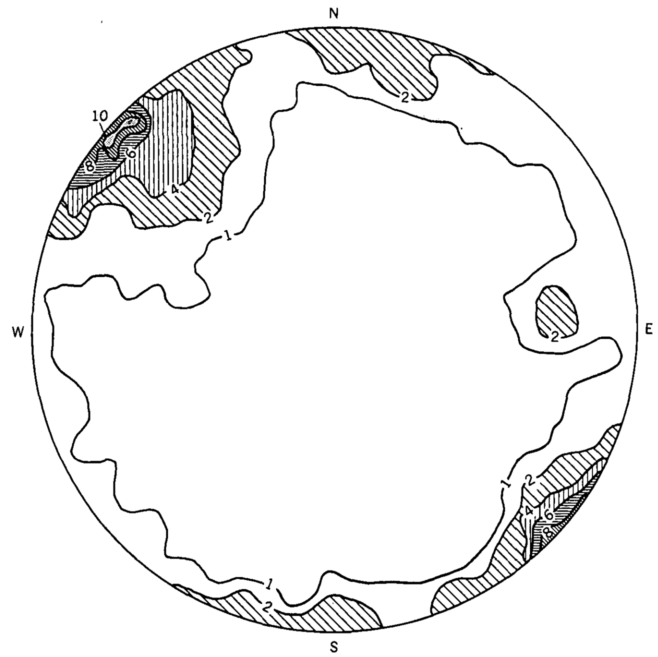

FIGURE 17.—Equal-area diagram of poles of 1,658 joints in the Texas Canyon quartz monzonite. Lower hemisphere projected. Contoured at 1, 2, 4, 6, 8, and 10 percent

aplite which was intruded along them at places. They are locally mineralized by seams of quartz in which huebnerite was detected at a few places. Only the joints that carry quartz are shown on the geologic maps (pls. 1, 6).

LITHOLOGY

The quartz monzonite is divisible into porphyritic, nonporphyritic, and sheared facies. The porphyritic type is by far the most widespread and is the main facies. The nonporphyritic type is a variant of this found near some contacts but is not confined to the contact zone. The sheared facies which is crushed and recrystallized, locally even gneissic, is found at the south end of the mass. The three facies have been mapped together and are described in the following paragraphs. Another facies characterized by quartz-muscovite and clay alteration, and which occurs as bands and lenses generally associated with quartz veins, has been mapped separately and is described on page 157.

The porphyritic and scarce nonporphyritic facies are pale brown on weathered surface and light gray to flesh colored on fresh fracture. The porphyritic type consists of phenocrysts of potassium feldspar 1 to 10 cm long (average 3 or 4 cm) in a medium-grained groundmass of quartz, feldspar, and biotite. Some of the quartz is in conspicuous subhedral crystals and aggregates 3 to 10 mm in diameter. In most outcrops the potassium feldspar phenocrysts make up 2 to 5 percent of the rock and are uniformly distributed without evident parallelism. Small inclusions of the groundmass constituents may be seen in some of the phenocrysts with a hand lens, particularly in their outer zones.

A study of thin sections of all the relatively unaltered specimens indicated a quartz monzonite containing 30 to 35 percent quartz, 30 to 40 percent plagioclase, 25 to 30 percent potassium feldspar, and about 5 percent mica. Most of the mica is biotite, but in some specimens biotite and muscovite are nearly equal in amounts. The plagioclase occurs as euhedral to subhedral crystals, commonly 1 to 4 mm long. The plagioclase is intermediate oligoclase, zoned from about Ab_{75} An_{25} in the centers to Ab_{95} An_5 at the margins. Interstitial to the plagioclase crystals are somewhat smaller anhedral grains of quartz and potassium feldspar, which gives the groundmass of the rock a monzonitic texture. The potassium feldspar in the phenocrysts and in the groundmass is, in part, microcline, but some lacks visible quadrille twinning and may be orthoclase. Microcline perthite of the replacement vein type is found both in the groundmass and as phenocrysts. The larger quartz masses are in part single subhedral crystals but much more commonly are aggregates of fairly large anhedral grains which are intricately interlocked, one grain commonly surrounding and including another. Quartz also occurs in small irregular to rounded grains and in myrmekitic intergrowth with late albite. The biotite is well scattered in small plates and in aggregates of several plates. The primary accessory minerals include magnetite, apatite, and a little zircon.

The common alteration of the porphyritic and nonporphyritic facies consists of sericitization of the plagioclase and chloritization of the biotite. All stages of sericitization of plagioclase are represented. In some specimens there is a little epidote or calcite with the sericite. The biotite is partly altered to chlorite, with or without accompanying epidote, rutile, and muscovite. The potassium feldspar is generally unaltered.

The sheared facies at the south end of the main mass ranges from rocks in which there has been minor granulation and recrystallization to granoblastic gneiss in which foliation is formed by tiny augen of feldspar and stringers of recrystallized quartz and biotite. The recrystallized plagioclase is generally unzoned, untwinned, and free from alteration products, whereas remnants of the original plagioclase are still much sericitized. Epidote and zoisite are more abundant than in the main facies. We regard the sheared facies as an early-solidified shell which was sheared by the friction of partly liquid and still-moving magma below it.

The sheared facies contains inclusions of biotite schist ranging from a few inches to a few score feet in length. They generally have gradational contacts, and some of them are represented by cloudlike masses resembling the sheared quartz monzonite except for an abnormally high content of dark minerals. Evidently reactions between the magma and included matter took place so that the same minerals formed in the inclusions and in the host rock. Constituents probably moved from magma into inclusions and vice versa.

AGE

The Texas Canyon quartz monzonite was emplaced after the post-Early Cretaceous orogeny and before the Tertiary and Quaternary alluvium was deposited. The quartz monzonite intrudes the Bisbee group and truncates major folds and faults which affect that formation (pl. 2, section *P–P′*). A pile of nearly horizontal post-Early Cretaceous thrust plates in lower Sheep Basin are uniformly contact metamorphosed (pl. 2, sections *N–N′* and *O–O′*). Evidence of forceful intrusion of the quartz monzonite suggests that orogenic forces were still operating during the early stage of emplacement. The most probable time of intrusion is early Tertiary, at the close of the Laramide revolution.

The Stronghold granite (Gilluly, 1956, p. 106) of the Dragoon Mountains evidently corresponds in age to the Texas Canyon quartz monzonite. This granite is younger than the post-Cretaceous thrusts in that area and resembles the Texas Canyon quartz monzonite in lithology and topographic expression. The compositional difference is not great, and both formations could be part of the same large intrusive body.

APLITE

The Tertiary(?) aplite is closely associated in space with the Texas Canyon quartz monzonite. In the central part of the quartz monzonite stock, there are scarce small aplite dikes; most of these follow joint planes. They are not confined to a particular set of joints except locally. Dikes are more abundant and generally larger in the marginal part of the stock; some are found in the wall rocks as much as half a mile from the nearest exposed quartz monzonite. Also there are large irregular aplite bodies at and near the boundaries of the stock. Apophyses and outlying intrusive bodies are more commonly aplite than quartz monzonite. At a few places, as in the NE¼ sec. 22, T. 16 S., R. 22 E., apophyses have a core of quartz monzonite and ends and margins of aplite.

Only the irregular intrusive bodies and the largest dikes are shown on the geologic map (pl. 1). The irregular bodies are shown in generalized form as they commonly fray off into the quartz monzonite as dikes and stringers that are too small to show at the scale of the map. At such places the contact was drawn where aplite becomes predominant.

The greatest concentration of aplite is in the general vicinity of Adams Peak where the stock is not completely unroofed. In addition to the large masses shown on the geologic map, there are in this area a host of small dikes trending north to northwest along a locally well developed set of joints in the quartz monzonite. Two miles north of the peak, these joints and many small aplite dikes strike about N. 50° W. and dip 55° to 75° NE. Toward the south the strike swings gradually to a northerly direction and the dip steepens to vertical. South of Adams Peak, dikes are found also along the predominant northeastward-trending joints. The shape of the large irregular mass forming Adams Peak was controlled by both joint sets. Dikes are very abundant in the thrust-faulted rocks at the lower end of Sheep Basin and have the same trends as in the quartz monzonite nearby.

Near what is regarded as the northeastward-plunging roof south of Johnson there is also a concentration of aplite. There are irregular masses along the quartz monzonite contact and also apophyses and dikes with several trends (pl. 6).

The aplite is considerably more resistant than the quartz monzonite. Most of the dikes are too small to be expressed topographically, but the large masses form conspicuous hills like Adams Peak. The outcrops on these hills are rough or jagged in form and light gray to white, contrasting with the rounded pale-brown outcrops of the quartz monzonite.

LITHOLOGY

The typical aplite is a sugary-textured white to yellowish-gray rock in which quartz, feldspar, muscovite, and in some specimens a little biotite are distinguishable with a hand lens. In thin section it is a mosaic of polygonal but anhedral grains about 0.5 mm in diameter. Scattered grains as much as 1 or 2 mm across are common, and in places the average grain size is 1 or 2 mm. The estimated mineral composition is 40 to 45 percent quartz, 25 to 35 percent microcline, 20 to 30 percent albite, and about 5 percent muscovite (and biotite if present). The accessory minerals are magnetite, apatite, zircon, and locally garnet. All thin sections examined show the effects of strain by undulatory and fragmentary extinction in the quartz, by deformation twinning and distortion of albite crystals, and by bending of mica plates. In some specimens a weak dimensional orientation of the constituents suggests dynamic metamorphism. The strain effects seem to be related to the aplite rather than to later regional forces, because they are more common and conspicuous in aplite than in quartz monzonite, which is an older rock.

Small amounts of pegmatite are very common in intimate association with the aplite. The pegmatite forms a few small separate bodies but more commonly is found within aplite bodies, concentrated near the borders or in internal patches and bands. The commonest occurrence is in thin parallel bands that give the aplite a layered structure. The layering in the large bodies near Adams Peak has the same attitude as the most abundant dikes. The relations suggest that movements occurring after the aplite had largely but not wholly solidified resulted in fractures now marked by concentrations of pegmatite. Filter-press action could explain the segregation of residual pegmatite-forming fluids and also the strain effects in the aplite.

The pegmatite varies in character from place to place. The simplest type consists of coarse interlocking crystals of microcline, quartz, and subordinate muscovite. Some of the quartz is intergrown with microcline to form graphic granite. In a more complex type, arborescent tufts of muscovite associated with albite have encroached on and replaced the microcline. The replacing albite is in small grains with random orientation. In extreme examples the microcline is completely replaced and the rock consists mainly of granular albite, quartz, and arborescent muscovite. Some of the quartz retains its graphic or cuneiform shape, which proves the replacement origin outlined.

Neither the simple pegmatite nor the albitized pegmatite contains tourmaline, beryl, or any unusual pegmatite minerals. Quartz veins intimately associated with the pegmatite contain a little muscovite, microcline, fluorite, pyrite, and iron oxides but no other minerals so far as known.

AGE AND ORIGIN

The geologic relations strongly suggest that the aplite is genetically related to the quartz monzonite magma. Dikes are very abundant in the quartz monzonite stock and cut the immediately surrounding rocks on all sides. The only places where dikes occur as much as half a mile from exposed quartz monzonite are in places where subsurface extensions of the quartz monzonite are probable at shallow depths. Several apophyses of quartz monzonite merge into aplite at their edges and terminations, and most of the outlying dikes are aplite rather than quartz monzonite. Thus it would appear that the aplite magma was the more mobile fraction of the quartz monzonite magma, probably a rest magma separated by filter-press action after partial crystallization of the quartz monzonite. The aplite fraction was intruded at intervals over an appreciable span of time. In the area of gneissic quartz monzonite at the south end of the Little Dragoons, most of the aplite dikes are no more sheared than dikes outside the sheared area which indicates that they are younger than the shearing. There are, however, a few much sheared dikes which evidently were intruded before the shearing. As far as known the aplite is all older than the quartz-tungsten veins. Most of it is older than the lamprophyre dikes, but one aplite dike cuts a lamprophyre dike in the zone of overthrust faults at the lower end of Sheep Basin. The aplite is younger than the Tungsten King fault (pl. 2, section *O–O′*).

LAMPROPHYRE DIKES AND PLUGS

Dikes, sills, and plugs of dark igneous rock, classified as lamprophyre, have intruded the Tertiary(?) aplite and older formations. Most bodies are small, and in general only the relatively large and conspicuous bodies are shown on the geologic map (pl. 1). The greatest concentration is near the Johnny Lyon Hills, where swarms of dikes and sheets have invaded the Paleozoic and older rocks in several structural sets that are conspicuous on the geologic map (pl. 1). Individual dikes in this area have widths of 1 to 40 feet and rarely as much as 75 feet. Some can be followed for 3 miles or more; these cross all major structural features in their path.

In the southern part of the Little Dragoons, small dikes cut the Texas Canyon quartz monzonite and the Tertiary(?) aplite. These dikes are widely spaced and generally nonpersistent, but one north-south dike 20 feet wide can be followed for 1½ miles in upper Sheep Basin. West and east of the Texas Canyon stock, many dikes have invaded the Pinal schist, Tungsten King granite, thrust plates of pre-Tertiary formations, and normal faults that postdate the thrust faults. The late normal faults invaded include the large Tungsten King fault and east-west faults that offset the Tungsten King fault. In the northern part of the Little Dragoons there are small dikes and irregular plugs in the Pinal schist and scarce thin sills in the Paleozoic sedimentary rocks. Lamprophyre outcrops have not been recognized near Johnson but lamprophyre was cut in the Peabody mine as shown by material on the dump.

A few small dikes and a crescentic plug 300 by 100 feet were found in the Gunnison Hills; but no lamprophyre was noted in the Steele Hills or the parts of the Dragoon and Winchester Mountains within the Dragoon quadrangle.

LITHOLOGY

The lamprophyre comprises a considerable range of textural and compositional types, but these types have some family resemblance. Plagioclase laths originally made up more than half of all but a few local phases. Euhedral to subhedral crystals of hornblende, and locally of augite, or brown biotite occur in the least altered specimens. The hornblende is characteristically pleochroic in pale yellow, reddish brown, and olive brown and has $(-)$ $2V=75°$ to $80°$ (est.), $r<v$, and

$Z \wedge c$ 15° to 17°; it is probably titaniferous. Magnetite, apatite, and sphene are conspicuous accessories. Deuteric or possibly hydrothermal calcite, chlorite, and epidote are invariably present and in some specimens obliterate the igneous minerals and textures. Amygdules, which are found in some of the fine-grained dikes, are composed of varying proportions of calcite, chlorite, quartz, epidote, and alkalic feldspars.

A porphyritic variety of the lamprophyre forms dikes as much as 20 feet wide in a northeastward-trending belt through the Johnny Lyon Hills; this belt parallels the zone of Precambrian intrusive sheets in the Pinal schist. Similar rock forms a few widely scattered dikes in the Texas Canyon quartz monzonite and older rocks in the southwestern part of the Little Dragoons. The porphyritic lamprophyre is green to olive gray. It is characterized by 10 to 25 percent prismatic phenocrysts or pseudomorphs of hornblende 1 to 5 mm long in an aphanitic to very fine grained groundmass. Fragmental inclusions of dark-green mafic rock 1 to 5 cm in diameter are common. Small white phenocrysts of plagioclase are much less common. The groundmass is gray green, microcrystalline, and sparsely amygdaloidal. The phenocrysts generally show strong flow orientation parallel to the dike walls. The hornblende phenocrysts are generally altered to chlorite, epidote, and calcite. The groundmass is mostly albite but contains also chlorite, epidote, magnetite, sericite, traces of apatite, zircon, and sphene; some specimens contain a little quartz. The rock has the general characteristics of spessartite.

Nonporphyritic lamprophyre is more common than the porphyritic type and shows greater variations in composition and texture. The texture ranges from aphanitic to coarse grained and the color from green or olive gray to nearly black. The coarsest and least altered varieties commonly contain prismatic dark green to black hornblende crystals 3 to 10 mm long, randomly orientated in a background of white plagioclase feldspar. Dikes of this rock commonly have chilled margins and also show considerable internal variation in grain size. Alteration to chlorite and other low-temperature minerals was pervasive.

Nonporphyritic lamprophyre dikes are very common in the Johnny Lyon Hills area. The largest dike, generally about 45 feet wide, trends N. 65° E. and is exposed at intervals for 3 miles, between the alluvial cover in sec. 25, T. 15 S., R. 20 E. and the NE¼ sec. 21, T. 15 S., R. 21 E. In this distance it cuts at least four major thrust faults. Due south of Keith Ranch it cuts across a dike of porphyritic lamprophyre, establishing the relative age of the two types at least locally. Where the nonporphyritic dike cuts the Abrigo formation southeast of Keith Ranch, it is bordered by a contact metamorphic zone 50 to 150 feet wide in which shale beds have been converted to epidote-clinozoisite hornfels and the limestone has been converted to grossularite-bearing marble; limestone inclusions in the dike are surrounded by fringes of hornblende, actinolite, and tremolite crystals as much as 6 inches long and 1 inch thick. Other nonporphyritic dikes, 1 to 40 feet wide, cut the Johnny Lyon granodiorite north and west of the Johnny Lyon Hills. Many but not all of these dikes trend north-northwest.

The nonporphyritic lamprophyre in the Johnny Lyon Hills, in its least altered form, has the mineral composition of diorite and consists of about 40 percent hornblende, 5 percent augite, and 55 percent feldspar. Most of the hornblende is brown and euhedral, but a little green hornblende is generally present. The augite is colorless and probably diopsidic. The feldspar is predominantly albite (An_{5-10}), but a little perthite and antiperthite may be present. The conspicuous accessories are apatite, iron oxides, and abundant sphene. This rock, like the porphyritic lamprophyre, is a spessartite in character, but it has a different texture and probably contains more TiO_2 (sphene) and K_2O. Locally the rock grades to a hornblendite with 90 percent or more amphibole.

Rocks with the same texture as the normal and hornblendite facies of the "diorite" lamprophyres of the Johnny Lyon Hills are found in some of the larger lamprophyre bodies in the Little Dragoons. Examples include the dike in the Peabody mine and the long north-south dike cutting the Texas Canyon quartz monzonite in upper Sheep Basin. Some of these dikes contain enough interstitial and replacement orthoclase to approach the mineral composition of monzonite. A little quartz is intergrown with the interstitial orthoclase at many places. At one place along the dike in upper Sheep Basin, the lamprophyre is associated with a fine-grained yellowish-gray rock that seems to represent a later injection along the same fissure. This later(?) rock is nearly 90 percent albite in laths about 0.5 mm long. Flakes of biotite and granules of epidote are scattered through the albite; intergrown quartz and orthoclase form an interstitial filling. The albite is turbid and partly replaced by orthoclase.

Nonporphyritic lamprophyre containing calcic plagioclase instead of albite was found in several small fine-grained dikes in the Texas Canyon quartz monzonite. The least altered specimens contain 50 to 60 percent lath-shaped labradorite (An_{60-65}), about 25 percent euhedral to subhedral crystals (or pseudomorphs) of hornblende, and either augite or brown biotite. Orthoclase, quartz, chlorite, and calcite are interstitial to these minerals. Apatite and abundant titaniferous(?) magnetite are conspicuous accessory minerals. The hornblende in the hornblende-biotite type is invariably much altered, whereas that in the hornblende-augite type may be nearly fresh. The calcic plagioclase is commonly partly replaced by albite and orthoclase. Pervasive calcite-chlorite alteration has affected many parts of the rock.

Many lamprophyre dikes are so altered to low-temperature minerals that igneous minerals and textures are not discernible. Specimens that consist mainly of chlorite and calcite are common.

AGE

The principal lamprophyric types have been found cutting the Texas Canyon quartz monzonite. They also cut the associated aplite at many places, but aplite cuts lamprophyre at one place in lower Sheep Basin. This suggests that aplite and lamprophyre overlap in age and that the lamprophyre is somewhat younger than the aplite for the most part. The lamprophyre appears to have been virtually contemporaneous with mineralization associated with the quartz monzonite. Lamprophyre dikes cut quartz-tungsten veins in the eastern part of the stock, but petrographically similar lamprophyre has undergone pyrometasomatic mineralization in the Peabody mine at Johnson (Cooper, 1957, p. 593–594). The evidence suggests that both lamprophyre and aplite are genetically related to the Texas Canyon quartz monzonite and were emplaced soon after it. They are no older than Late Cretaceous and are probably early Tertiary.

Our assignment of all the lamprophyre in the area to this epoch is based on petrographic and structural evidence. The major lamprophyric types in the Johnny Lyon Hills area are petrographically similar to types cutting the Texan Canyon quartz monzonite. Geologic relations tend to support a correlation, for these dikes in the Johnny Lyon Hills are younger than post-Paleozoic thrust and normal faults but older than northeastward-trending rhyolite dikes, of Tertiary age which cut "diorite" lamprophyre at several places.

As criteria for close dating of many individual bodies of lamprophyre are lacking, some lamprophyre that predates the Texas Canyon quartz monzonite may be present. If so, we believe it is subordinate to the younger lamprophyre. In general the bodies are free from deformational effects though some have been sheared locally. A sheared specimen from the Tungsten King mine is shown in figure 30. The obvious intensity of the shearing might be taken as an indication of pre-Laramide age for this lamprophyre if the shearing were not a local phenomenon in a dike that was emplaced along a post-thrusting normal fault. The deformation is also obviously younger than tungsten mineralization which was probably contemporaneous with mineralization in the Texas Canyon quartz monzonite. For these reasons, the shearing is regarded as a postquartz monzonite phenomenon like the local but intense shearing of tungsten veins in the quartz monzonite and the development of schistosity in the altered rock next to them. The total movements involved probably were not great.

PRE-THREELINKS UNCONFORMITY

The base of the Threelinks conglomerate is a major unconformity, which represents an orogeny second only to the orogeny between the earlier and later Precambrian. In the Steele Hills, the Threelinks conglomerate lies with gentle dips on closely folded and even overturned Cretaceous rocks. Therefore the major folds and overthrust faults involving the Mesozoic, Paleozoic, and late Precambrian formations were formed in the interval between Cretaceous and Threelinks time. The Texas Canyon quartz monzonite, aplite, and lamprophyre were probably intruded during this interval also, although their emplacement followed the major deformation, and they are not found in contact with the Threelinks conglomerate. After these events, which are considered part of the Laramide orogeny of the Rocky Mountain States, the area was uplifted and deeply eroded but not reduced to a peneplain. The Threelinks conglomerate is a terrestrial deposit that contains large boulders and appears to have been laid down on a surface of considerable relief.

TERTIARY SYSTEM

THREELINKS CONGLOMERATE

The name Threelinks conglomerate is here applied to the conglomerate and intercalated sands, silts, and lava flows that lie unconformably on the Cretaceous strata and below the Galiuro volcanics. The type section is at the southeast end of the Steele Hills, on the Threelinks Ranch.

The Threelinks conglomerate is exposed on the south and east sides of the Steele Hills and in Kelsey Canyon near the northwest corner of the quadrangle. Rocks at the south end of the Winchester Mountains are referred doubtfully to the formation. At all three localities, the formation is nonresistant and has been eroded to low elevations where unprotected by slide rock from above. The protective covering of talus has been breached at many places in the Steele Hills with the result that slopes underlain by the Threelinks are much gullied and contrast with the smoother surface cut on the overlying rhyolite that caps the hills. In the banks of recently incised arroyos, the Threelinks generally stands in steep slopes.

STRATIGRAPHY

The basal contact of the Threelinks conglomerate has not been observed because of faults and cover of soil, slope wash, and alluvium. At the south end of the Steele Hills the Threelinks has gentle dips and evidently lies on a surface that truncates closely folded beds of the Morita and Cintura formations (pl. 1; pl. 2, section *J–J'*). In the Winchester Mountains and in Kelsey Canyon, the nature of the basal contact is indeterminate, and there is uncertainty regarding the proper lower limit of the formation.

The Galiuro volcanics have an overlapping relation to the Threelinks. In Kelsey Canyon and in the Winchester Mountains, the basal (andesite) member of the Galiuro overlies the Threelinks. In the Steele Hills the lower members of the Galiuro are missing, and the upper rhyolite member lies directly on the conglomerate. In this area the top few inches to few feet of the conglomerate are deeply stained and partly replaced by manganese oxides, which are evidently a product of deep prerhyolite weathering. This deep weathering probably correlates with the unconformity everywhere present at the base of the rhyolite member and therefore is probably intra-Galiuro and not pre-Galiuro in age. The Threelinks conglomerate in the Steele Hills could be the same age as the lower part of the Galiuro sequence farther north.

If the evidence at the south end of the Winchester Mountains has been interpreted correctly and the beds there mapped as Threelinks conglomerate are in fact a lower member of that formation filling a pre-Threelinks valley, local angular discordance between the Threelinks and the basal member of the Galiuro volcanics is indicated (fig. 18). The andesite lava flow in the Threelinks which is several hundred feet stratigraphically below the Galiuro volcanics in its eastern exposures approaches the Galiuro volcanics and is truncated by them on the west. In this area a resistant gray limestone bed separates the Galiuro volcanics from the underlying rocks. This limestone bed ranges from 0 to about 20 feet in thickness and has been traced for nearly a mile immediately beneath the Galiuro volcanics. It is not shown on the geologic map (pl. 1) because of scale limitations. The limestone probably was deposited in a temporary lake formed by damming of the then-existing drainage by early eruptions belonging to the Galiuro volcanics. It could be a hot-spring deposit. In either case the attitude of the limestone was determined by the surface on which it was deposited and is not nesessarily parallel to bedding in the rocks below.

The unconformity at the base of the Galiuro volcanics in the Winchester Mountains is considerably older than the one in the Steele Hills. Our tentative interpretation (fig. 18) that the older surface passes below the Threelinks conglomerate in the Steele Hills is based on lithologic characteristics which suggest that the Threelinks in the Steele Hills may be the time equivalent of the lower members of the Galiuro volcanics. No field evidence that the Threelinks interfingers with these members was found.

CONGLOMERATE

Conglomerate makes up most of the formation but good outcrops of the conglomerate are scarce. It was necessary to rely very largely on float in mapping.

In the type area in the Steele Hills, most outcrops are weakly consolidated conglomerate consisting of subangular pebbles and cobbles in a matrix of yellowish-pink feldspathic sand. The fragments include rocks as old as late Paleozoic and as young as the Cretaceous(?) sedimentary and volcanic rocks. Still older forma-

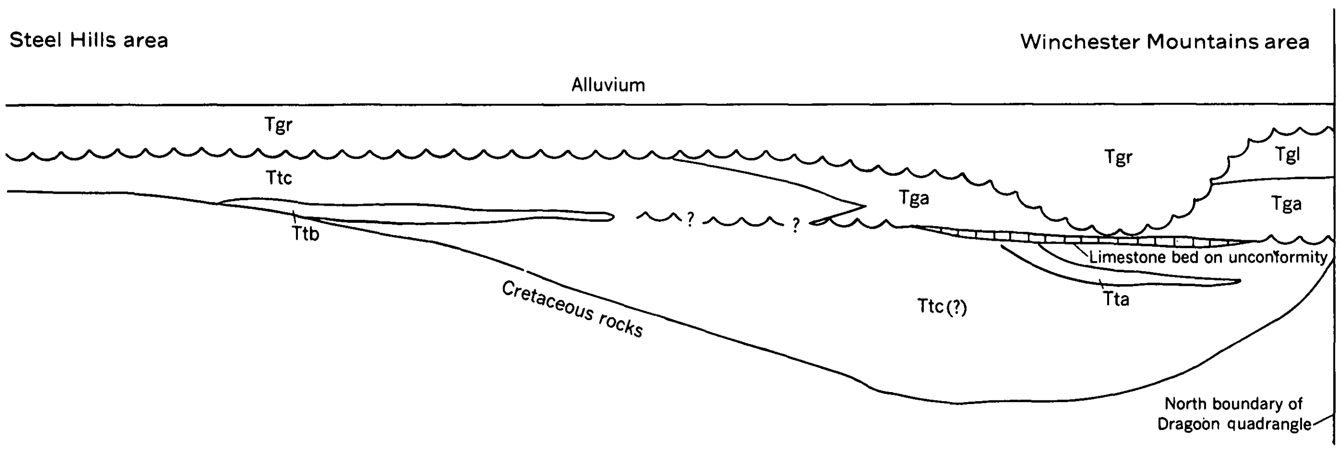

FIGURE 18.—Diagrammatic section showing the stratigraphic relations of the Threelinks conglomerate and the Galiuro volcanics; the Galiuro volcanics, rhyolite member (Tgr), latite member (Tgl), and basaltic andesite member (Tga); the Threelinks conglomerate, conglomerate member (Ttc), andesite member (Tta), and basalt member (Ttb).

tions may be represented, and locally there are abundant fragments of pink clay thought to have been derived from volcanic glass of the Galiuro which was accumulating to the north at the time this facies of the conglomerate was laid down. A distinctive feature of the conglomerate is the presence here and there of rounded boulders, several feet in diameter, of Glance conglomerate, quartzite, and olive-colored feldspathic sandstone. The boulders weather out on the surface and are very useful in mapping from float. They led to our field name "boulder bed" for the unit. In gullies and other places where there are good exposures, much fine clastic unconsolidated sediment is seen between conglomerate beds. The finer unconsolidated sediments are well-bedded yellow sand and silt.

At the south end of the Winchester Mountains, the conglomerate assigned doubtfully to the Threelinks differs from that in the type area in having steeper dips, a deep red rather than a yellow matrix, generally more rounded boulders, and a higher proportion of volcanic fragments. Many of the boulders were fractured subsequent to deposition, and the more easily weathered boulders are softened and even disintegrated. The conglomerate is interbedded with purple sandstone and red and gray silt. The assemblage resembles the middle (transitional) part of the unnamed Cretaceous(?) sedimentary and volcanic rocks to the east although fracturing and weathering of boulders was not noted in the Cretaceous(?) rocks. The field relations permit assignment either to the Threelinks or to the unnamed formation.

The rocks of doubtful affiliation were assigned to the Threelinks conglomerate rather than the Cretaceous(?) for the following reasons: (1) They are nearly parallel to the Galiuro volcanics in attitude; in the northern outcrops they strike northeast normal to the general northwest strike of the Cretaceous rocks. (2) They are full of fragments of quartzite, limestone, and other sedimentary rocks absent from the nearby outcrops of the volcanic member of the Cretaceous(?). (3) They are generally less indurated and more weathered than the Cretaceous(?) beds. Where mapping was by float as it was in much of the area, criteria are lacking to distinguish the rock from typical Threelinks. We tentatively interpret the beds as a lower valley-filling member of the Threelinks (fig. 18). The hypothetical pre-Threelinks valley trends northwest between the two prongs of the Winchester Mountains (pl. 1). In the northeastern corner of the quadrangle, the conglomerate seems to wedge out. The geologic relations in this area are concealed by post-Galiuro landslides, but the concealed interval between Cretaceous(?) rocks and Galiuro volcanics in place is only 200 feet wide at one place. Thus the questionable unit is either absent or very narrow. A mile or two north of the quadrangle boundary, in Severin Canyon, the conglomerate is again exposed beneath the Galiuro volcanics.

As an alternative interpretation, the questionable rocks might be considered part of the unnamed Cretaceous(?) sedimentary and volcanic rocks. This would require a local strike deflection in that formation that happened to conform with a corresponding deflection in the Galiuro volcanics. It is hard to accept such fortuitous parallelism, but the interpretation would give a plausible explanation of the disappearance of the unit toward the east, namely that it turns northward beneath the volcanic pile.

About 10 miles to the west in Kelsey Canyon, the Threelinks conglomerate underlies the basal andesite member of the Galiuro volcanics, and the two units appear to be concordant. The Threelinks is similar in general to that in the Steele Hills and consists of conglomerate with beds of well-stratified yellow sand and silt. Fragments of andesite of Cretaceous(?) age are abundant in the conglomerate. Between these beds and the Paleozoic rocks to the south are beds of red limestone conglomerate in which no volcanic fragments were found. The change in lithology appears to be sharp but exposures are poor and the relation between the two conglomerates is nowhere actually exposed. The red conglomerate lies unconformably on the Horquilla limestone without angular discordance. As the tilting of the Paleozoic rocks is a regional structural feature apparently related to the Late Cretaceous or early Tertiary orogeny that preceded deposition of the Threelinks, the limestone conglomerate is here tentatively assigned to the Glance. The sudden appearance of the red conglomerate and its lack of volcanic fragments tend to support this conclusion, but the conglomerate may be a lower member of the Threelinks. The red conglomerate is better cemented than most of the Threelinks. It is more distinctly bedded and less well cemented than the Glance in other parts of the area.

BASALT FLOW

A basalt flow about 60 feet thick is intercalated in the conglomerate on the southeast side of the Steele Hills (pl. 1; pl. 2, section *J–J′*). The basalt is purplish gray in outcrop and hand specimen and shows conspicuous plagioclase phenocrysts in an aphanitic groundmass. The plagioclase phenocrysts are laths and tablets ¼ to 1 inch long. Small phenocrysts of magnetite and pyroxene and small patches of greenish-yellow serpentinous material are distinguishable with a hand lens. The groundmass is finer toward the top and bottom of the flow. The top is vesicular and generally brick red. Many of the vesicles are partly filled with chalcedony, calcite, and blue-green fibrous celadonite. Several old prospect pits appear to have been dug because the celadonite was mistaken for a copper mineral.

The plagioclase phenocrysts are labradorite (about An_{55}) that is fresh and little zoned. Other phenocrystic constituents are augite, magnetite, and bowlingite(?) pseudomorphs after some ferromagnesian mineral. The groundmass consists of tiny calcic plagioclase laths, which have albitic rims, irregular to subhedral magnetite, and abundant interstitial matter. The interstitial matter is too fine grained for positive identification but appears to include albitic feldspar and needles of apatite. The rock is very similar to the basaltic andesite member of the Galiuro volcanics although the plagioclase is a little more calcic and hypersthene was not identified.[8]

ANDESITE FLOW

Andesite crops out at three places in the Threelinks(?) conglomerate of the Winchester Mountains (pl. 1). We regard the three outcrops as part of a single lava flow intercalated with the conglomerate (fig. 18). The basal contact is exposed at one place and is concordant. The upper contact is not exposed, but boulders of the andesite are found in the overlying conglomerate.

The andesite is a fine-grained pinkish-gray rock that weathers brown. It is speckled with aggregates of rusty-brown material about 1 mm in length which are evidently pseudomorphs after a ferromagnesian mineral. Small phenocrysts of green pyroxene, specks of magnetite, and minute feldspar laths are distinguishable with a hand lens.

As seen under the microscope, the rock is little altered except for the brown pseudomorphs which have relatively thick rims of iron oxides and small cores of beidellite(?). The primary mineral that gave rise to these secondary products is not known. The groundmass is a holocrystalline intergranular aggregate of plagioclase and augite which contains disseminated magnetite and needles of apatite. Plagioclase, in subparallel laths about 0.2 mm long, makes up about three-quarters of the groundmass. The crystals are zoned and range from intermediate labradorite at the centers to oligoclase at the margins. Most of the augite is in small subhedral grains, but some is euhedral and in crystals as much as 1 mm in length.

THICKNESS

No stratigraphic measurements of the Threelinks conglomerate were made because of poor exposures. From the dip and location of contacts on the topography a thickness of 50 to 125 feet is inferred at the south end of the Steele Hills and at least 700 feet at one place on the east side of the hills. The greatest thickness of the doubtfully classified rocks in the Winchester Mountains appears to be about 2,000 feet. The estimates are subject to substantial error because of scarce data on the attitude and the possible presence of concealed faults. As both upper and lower contacts of the formation are unconformities, local variation in thickness is to be expected.

AGE AND CORRELATION

No fossils or other evidence were found to date the Threelinks conglomerate directly. The relation to other formations shows it is of Tertiary age but gives no basis for closer dating. It is in part older than the Galiuro volcanics and probably in part equivalent to the lower part of that formation. The stratigraphic position is somewhat analogous to that of the Whitetail conglomerate (Ransome, 1903, p. 46) that underlies the dacite in the Globe-Miami area though no contemporaneous volcanic rocks have been recorded in the Whitetail. The analogy is even closer with a conglomerate described by L. A. Heindl in a study of the San Pedro valley north of Redington. Mr. Heindl (written communication, 1954) described the formation as follows: "consolidated conglomerates including fragments up through lower (basaltic-andesitic) Galiuro sequence * * * and rhyolitic intrusives, not mineralized but involved in normal and thrust faulting."

Fragmentary plant fossils were found in the local limestone bed which overlies the Threelinks(?) and underlies the Galiuro volcanics in the Winchester Mountains. A collection of these fossils was examined by R. W. Brown of the Geological Survey who stated (written communication, Aug. 31, 1953): "The plant fragments in this collection consist of indeterminate striated stems. I shall not venture a guess concerning their age."

GALIURO VOLCANICS

The name Galiuro rhyolite was given by Blake (1902, p. 546) to the volcanic rocks of the Galiuro Mountains. These rocks are part of a great volcanic pile, some 75 miles long and 15 miles wide, that extends southward into the Dragoon quadrangle in the Winchester Mountains, Steele Hills, and Kelsey Canyon areas. As rock types other than rhyolite are represented in these southern exposures, we propose the more general name Galiuro volcanics for the entire volcanic pile.

[8] Unpublished chemical data obtained from several localities in southeastern Arizona since this report was written suggest that these "basalts" and "basaltic andesites" may both have the chemical composition of trachyandesite, considerable quantities of occult potassium feldspar and quartz being present in the groundmass.

STRATIGRAPHY

Only a small fraction of the total section of the Galiuro volcanics is represented in the Dragoon quadrangle. Our divisions and the general stratigraphic relations of this part are as follows:

	Feet
Conglomerate (probably equivalent to Gila conglomerate).	
Unconformity.	
Galiuro volcanics:	
Rhyolite member	900
Volcanic conglomerate	0–500
Unconformity.	
Latite member	0–300
Basaltic andesite member	0–456
Local unconformity(?).	
Threelinks conglomerate.	

The members are distinctive map units, but our petrographic names may have to be changed when chemical analyses are available. The names are based on microscopic study alone. As the rocks contain considerable groundmass material that cannot be identified under the microscope, this is an inadequate basis for classification.

The basaltic andesite and latite members constitute a lower part of the formation separated from the upper part of conglomerate and rhyolite by an unconformity. The lower members occur in the Winchester Mountains and in Kelsey Canyon. The conglomerate member is missing in the Winchester Mountains, and the rhyolite fills old valleys cut into and through the lower members. South of the Winchester Mountains the latite and basaltic andesite wedge out beneath the rhyolite member, and in the Steele Hills only the rhyolite is present (fig. 18). North of the quadrangle boundary the latite member thickens by the appearance of additional units at the top. In Kelsey Canyon the conglomerate unit separates the rhyolite and the lower members.

BASALTIC ANDESITE MEMBER

The basaltic andesite member is considerably more resistant than the underlying Threelinks conglomerate but less resistant than the overlying latite unit. It is well exposed in the lower slopes of Kelsey Canyon and at the southwestern tip of the Winchester Mountains where it forms dark-colored slopes and ledges beneath impressive light-colored cliffs of the latite. The member consists of flows and subordinate pyroclastic rocks and is similar in appearance to the basalt flow in the Threelinks conglomerate but contains slightly less calcic plagioclase so that it appears to be on the border line between andesite and basalt in composition. Here it is called basaltic andesite. A section measured at the south end of the Winchester Mountains follows:

Section of basaltic andesite member of Galiuro volcanics

[Winchester Mountains (NE¼ sec. 2, T. 14 S., R. 22 E.)]

	Feet
Latite member:	
Vitric-crystal tuff, light-pink; weathers light tan.	
Basaltic andesite member:	
Basaltic andesite flow or flows, partly vesicular, brown to purplish-red; phenocrysts of plagioclase and pyroxene, and pseudomorphs of serpentinous material discernible in hand specimen. Largest phenocrysts near bottom where some plagioclase plates are more than 1½ in. across	129
Basaltic andesite tuff-breccia, rusty-red	8
Basaltic andesite flow, No. 3, top red and vesicular	72
Basaltic andesite flow No. 2, dark-gray; red slaggy top and soft green altered zone in upper part; phenocrysts of plagioclase and pyroxene conspicuous in porcellaneous groundmass	154
Basaltic andesite flow No. 1, weathering dark reddish to purplish brown with red top; phenocrysts of plagioclase, pyroxene, and serpentinous material in aphanitic groundmass that becomes porcellaneous toward top and bottom	73
Basaltic andesite tuff-breccia, largely covered	20
Total thickness of basaltic andesite	456
Threelinks conglomerate:	
Conglomerate with quartzite and limestone pebbles.	

In hand specimen the andesite is characterized by a striking porphyritic texture. Large tabular phenocrysts of plagioclase, ¼ to 2 inches in length, are set in an aphanitic brown or dark-gray groundmass. Much less conspicuous are scattered phenocrysts of nearly black pyroxene or its alteration products and specks of magnetite. The pyroxene phenocrysts are locally as much as a quarter of an inch in length but generally smaller. The composition averages about 25 percent plagioclase, 10 percent pyroxene, 1 percent magnetite, and 64 percent groundmass, but the proportion of constituents varies from place to place.

Under the microscope the plagioclase phenocrysts are generally andesine-labradorite ($An_{50\pm5}$) characterized by slight progressive zoning; albite and carlsbad twinning are conspicuous. The pyroxene is in part pigeonitic clinopyroxene and in part hypersthene. Magnetite and apatite are the primary accessory minerals. Plagioclase and clinopyroxene phenocrysts are present in every thin section studied and are generally unaltered. Hypersthene is not present in every specimen, but where it is absent, and apparently only where it is absent, there are pseudomorphs of bowlingite(?) with shapes similar to the hypersthene. Of two specimens from a single flow, one may have completely fresh hypersthene but no bowlingite(?) pseudomorphs, whereas the other has pseudomorphs and no hypersthene. These facts lead us to believe that most of the bowlingite(?) was derived from hypersthene, although no unreplaced cores of hypersthene were found in the bowlingite(?), and in one specimen bowlingite(?) has partly replaced a clinopyroxene crystal. Bowlingite is generally a replacement product of olivine and this origin cannot be ruled out completely for some of the bowlingite(?) in these rocks.

The groundmass of the rock is characterized by minute oligoclase-andesine (An_{25-40}) laths, clinopyroxene, iron oxides, and interstitial glass(?). Two of three specimens obtained in Kelsey Canyon have a very different kind of groundmass consisting mainly of a holocrystalline aggregate of irregular but nearly equant grains and intergrowths of albite. Some quartz is present. There are rims of albite around the andesine-labradorite phenocrysts. The peculiarities of this rock probably result from replacement by sodic solutions and are not a primary feature.

In the upper part of one flow in the Winchester Mountains (flow 2 of measured section) there is a persistent but irregular zone of alteration 10 to 20 feet thick. It is light gray green, soft, and very easily eroded. It consists mostly of clay of the montmorillonite type in which phenocrysts of plagioclase, clinopyroxene, and bowlingite(?) are still partly preserved. The groundmass material as seen in thin section has structure resembling the onionskin cracks of perlite but the unreplaced rock lacks perlitic structure. Perhaps the cracks were formed by shrinkage of the clay incident to dehydration some time during its history.

About half the thin sections examined from the basaltic andesite member contain small to medium-sized grains of minerals characteristic of acidic igneous rocks. These grains, which include quartz, biotite, and microcline, are rounded and embayed by the groundmass. The shape of the grains indicates they were soluble in the magma and partly resorbed as required by the reaction principle of Bowen (1928, p. 54–62). They are thought to be remnants of inclusions picked up by the magma. The material dissolved from the inclusions would make the magma more acidic than it was originally.

Vesicles and other cavities in the rock contain druses of chalcedony, opal, stilbite, perhaps other zeolites, and locally celadonite. Calcite, which is a conspicuous druse and replacement mineral in the basalt of the Threelinks conglomerate, was not observed.

LATITE MEMBER

Light-colored lava flows and pyroclastic rocks lie with apparent conformity on the basaltic andesite and form conspicuous cliffs and peaks, both in the Winchester Mountains and in the Kelsey Canyon area. These rocks, which are mapped as the latite member, thicken toward the north because of the appearance of additional units beneath the overlying conglomerate and rhyolite. The maximum thickness within the Dragoon quadrangle is about 300 feet both in Kelsey Canyon and in the Winchester Mountains. The petrographic details are notably different in the two areas and show that different eruptions and perhaps different centers of eruption are represented.

The lower part of the member in the Winchester Mountains is rhyolitic in composition as shown in the following partial section which is the continuation of the one given on page 88:

Section of rhyolite unit at base of the latite member

[Winchester Mountains (NE¼ sec. 2, T. 14 S., R. 22 E.)]

	Feet
Latite member:	
Top of ridge (impractial to measure higher units at this locality).	
1. Rhyolite, pink, banded; forms very conspicuous cliffs	176
2. Rhyolite, brown, banded; grades into unit above	15
3. Glass, black; with perlitic cracks and scattered phenocrysts	26
4. Vitric tuff, light-pink, porous, bedded; with light-tan weathered surface	25
Total thickness measured	242
Basaltic andesite member:	
Basaltic andesite flow.	

The vitric tuff at the base has a well-preserved and little modified pyroclastic texture. Hand specimens show numerous small fragments of pumice, mineral grains, and particles of rhyolite and andesite in a porous crumbly groundmass. The most abundant mineral fragments are of sanidine, oligoclase-andesine (An_{30}), biotite, and magnetite. The groundmass consists of abundant virtually undistorted shards and interstitial dusty material. The shards are outlined by lines of birefringent material and are partially devitrified around the edges to minute feldspar fibers standing normal to the shard surface. The centers are still glass or, in the most devitrified parts, tridymite. The interstitial material is apparently wholly devitrified but is too fine grained for mineral identification. Cavities in the rock are lined with tridymite and some with later formed quartz. The lithologic character and presence, at places, of discernible bedding indicate that this unit represents an ash fall.

The black glassy unit overlying the vitric tuff in the measured section is present at most if not all places where the base of the latite member is exposed in the Winchester Mountains. It is a shiny fresh-looking rock with conchoidal fracture and perlitic cracks. It was identified as a lava flow in the field, but study of thin sections renders this interpretation improbable. The groundmass is full of minute brown seams that outline lenticular and branching areas resembling much compressed shards. The laminae formed thereby bend around scattered phenocrysts and fragments of the same materials found in the underlying vitric tuff. There are also small nearly equidimensional patches of brown homogeneous glass. Rocks with this texture are interpreted by most modern petrologists as welded and thoroughly compressed tuffs, formed as a result of incandescent ash flows that were so hot the fragments were fused together and flattened by the weight of the mass. The glass layer seems too thin to provide the weight needed to cause the compaction observed, but it is possible that most of the weight came from overlying units, which, though very different in appearance, probably have the same composition and also have the characteristics of welded tuff. Thus the glass would represent the basal chilled facies of a much thicker unit, most of which is thoroughly devitrified.

The glass layer has sharp lower and upper contacts and appears to be uniform from top to bottom. It is perfectly isotropic with index of refraction very near 1.50. The only indication of devitrification consists of hairlike crystallites that stand normal to the brown seams that delimit the shards. The sharp lower contact with unwelded and uncompressed tuff suggests that this contact marks the base of the ash-flow unit. The sharp upper contact with welded but devitrified tuff may indicate that devitrification went on rapidly and virtually to completion when a particular set of conditions was reached.

Above the glass in the Winchester Mountains there is a very conspicuous cliff-forming unit that is about 200 feet thick and, in the measured section, is divisible into two parts (units 1 and 2 of section). The lower part is brown, and the upper part is bright pink and finely streaked parallel to the base with gray siliceous lenses averaging about half an inch in width. The two parts grade into one another, and both are hard and compact. The rock is aphanitic except for included rock fragments and phenocrystic constituents which are the same as in the glass below.

In the lower part the groundmass is dusty brown weakly birefringent material. The dusty material, which is too fine grained for mineral identification, contains minute colorless lenses consisting of potassium feldspar and quartz. These lenses, which are taken to be devitrified shards, are compressed and alined parallel to the base of the unit but bend over and under the phenocrysts and rock fragments. They are locally contorted as though by minor flowage of the rock after compression and alinement. There is evidence of the passage of mineralizing gases or liquids through the rock after it was rigid enough to sustain open fractures. Minute veinlets of quartz, generally with euhedral sanidine crystals along the margin, are common transverse to the lamination. Many of the veinlets have indistinct edges and are bordered by zones in which the groundmass loses its brown color and becomes more distinctly crystalline but does not lose the shard texture. Some of the plagioclase phenocrysts are replaced by sanidine around the edges and along cracks, and spherulitic potassium feldspar has formed around and within included rock fragments.

The upper and thicker part of the cliff-forming unit is generally similar to the lower part but lacks spherulitic texture and contains numerous small tabular lenses of quartz, generally with marginal sanidine. The lenses parallel the base of the unit and give the outcrops a distinct flow structure. The groundmass next to the lenses is bleached and more coarsely crystalline. The shard texture of the groundmass has been destroyed in the bleached borders. Some transverse quartz veinlets cross the parallel quartz lenses and others do not, which indicates that veinlets and lenses were formed at the same time. The plagioclase phenocrysts are more thoroughly replaced by sanidine than in the lower part of the unit, and the biotite is partly bleached.

We interpret the cliff-forming unit (units 1 and 2) and the glass layer (unit 3) as parts of a single thoroughly welded and compacted ash flow. The glass layer represents the basal chilled zone. The cliff-forming unit was devitrified and emitted hot gases rich in silicon and potassium. These gases moved upward through the mass and deposited the transverse quartz veinlets. Some gas permeated the upper part of the flow and formed the quartz-sanidine lenses, expedited devitrification, and altered the primary minerals.

The rocks just described are overlain in the Winchester Mountains by light-gray and light-purple latite flows which appear to differ from one another only in the color of the groundmass. Both are characterized by phenocrysts 1 to 4 mm long of plagioclase and biotite and pseudomorphs of limonitic material after hornblende. The plagioclase phenocrysts, which make up about 20 percent of the rock, are andesine showing progressive and oscillatory zoning in the range An_{40} to An_{50}. Some have abundant small inclusions of groundmass material in the outer parts. In one thin section potassium feldspar has partly replaced the phenocrysts around the edges and in interior zones and patches. Phenocrysts of biotite and hornblende together constituted about 10 percent of the original rock. The biotite is in books in which the diameter and thickness are about equal. The hornblende is almost completely replaced by iron oxides and other secondary products, but enough traces of the original mineral remain to reveal its identity. Magnetite, apatite, pigeonite(?), and zircon are microscopic accessory minerals.

The groundmass is best preserved in the gray facies of the rock where it consists of minute oligoclase-andesine laths, pale brownish-green mica, clinopyroxene, and specks of magnetite in an abundant glassy matrix. The prismatic constituents are subparallel to one another as a result of flowage of the lava. In the purple facies there is no magnetite dust but instead translucent red iron oxide which gives the rock its distinctive color. There is also more devitrification and fairly extensive replacement of the plagioclase by potassium feldspar. Vesicles are filled with quartz, commonly bordered on the outside by a rim of potassium feldspar. The apparent abundance of potassium feldspar in the devitrified groundmass material, in replacements of plagioclase, and in vesicle fillings is the reason we regard the rock as latite or quartz latite rather than dacite or andesite.

The latite member in Kelsey Canyon is similar superficially to the lower part of the member in the Winchester Mountains. There is a black glassy unit 15 to 20 feet thick at the base, overlain by a pink to light-purple banded cliff-forming unit several hundred feet thick. The petrography and origin of the rocks are different in the two areas however. The Kelsey Canyon facies lacks phenocrysts of sanidine, hornblende, and biotite and contains phenocrysts of augite and, in some specimens, hypersthene also. Because of microscopic textural features the Kelsey Canyon rocks are regarded as lava flows.

Thin-section examination of a fresh specimen of the glassy unit yielded the following estimated composition:

	Weight percent
Plagioclase	30
Augite	2
Hypersthene	2
Magnetite	1
Apatite	Trace
Quartz	Trace
Glassy groundmass	65

The plagioclase phenocrysts range from 0.1 to 4 mm in diameter and from euhedrons to angular fragments and much resorbed residuals. Progressive and oscillatory zoning is conspicuous; the composition ranges from An_{40-45} near the core to An_{30} at the rim. The augite and hypersthene are in anhedral grains 0.1 to 1 mm in diameter and in some places are included in the feldspar. The glassy matrix has innumerable crystallites and rare microlites of plagioclase. The matrix is fractured and there are some suggestions of a perlitic pattern. The index of refraction is 1.50, the same as in the Winchester Mountains unit. Irregular subparallel streaks as much as 1 mm wide and 20 mm long cross the thin section and swirl around the phenocrysts. These are regarded as evidence for origin as a lava flow.

The overlying cliff-forming unit seems to be a single lava flow, now separated into several areas of outcrop by block faulting and erosion. There is no unfaulted exposure of the entire member and the thickness can only be estimated at about 250 feet. The outcrops are flow banded in shades of pink, light purple, or brown. The bands are commonly ½ to 1 inch thick and have gradational contacts. There is frequently a parting plane every few inches which parallels the color bands and gives the rock a bedded appearance. Hand specimens show feldspar phenocrysts as much as 4 mm, smaller limonitic pseudomorphs after some ferromagnesian mineral, specks of magnetite, and abundant partly filled vesicles in an aphanitic groundmass. At one locality north of Kelsey Canyon, there are abundant geodes 1 to 5 inches in diameter commonly completely filled with opaline and chalcedonic silica.

Microscopic study suggests strongly that the cliff-forming unit has the same composition as the underlying glass. Phenocrysts of andesine (composition same as in glass unit), augite, limonitic pseudomorphs after some ferromagnesian mineral, magnetite, and apatite are embedded in a very fine grained groundmass presumed to be devitrified glass. The groundmass seems to be made up largely of minute laths of potassium feldspar, without preferred orientation, in a matrix of larger irregular grains of albite. Vesicles in the rock are partly or wholly filled with potassium feldspar, chalcedony (some of which looks as though it had replaced earlier tridymite), traces of calcite, and, in one specimen, a little very low index low birefringent material that may be tridymite.

CONGLOMERATE MEMBER

The conglomerate member is known only in Kelsey Canyon where it occurs in several fault blocks. In one outcrop it rests unconformably on a weathered glassy unit of the latite member. Elsewhere it was deposited on other units of this member and, in a small area, on basaltic andesite. Both local and regional relations indicate little if any angular discordance between the conglomerate and subjacent rocks. In the easternmost outcrop the conglomerate is overlain with apparent conformity by a massive and resistant welded tuff-breccia. This breccia is assigned to the rhyolite member on the basis of composition. The total thickness of the conglomerate member is at least 500 feet on the south side of Kelsey Canyon.

The conglomerate member is made up of conglomerate and intercalated tuff, volcanic breccia,

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and red sandstone. The structure ranges from well bedded to massive. Some parts are massive latite breccia that seems to be of pyroclastic origin; but most of the unit is moderately well bedded and consists of subangular to rounded fragments of latite and basaltic andesite as much as 1 foot in diameter, and some fragments of volcanic rock types not seen within the map area. In the upper 75 feet of the member, thin-bedded tuffaceous water-laid sediments are interbedded with a few thick-bedded vitric tuffs.

The member as mapped includes a conspicuous yellow vitric tuff unit about 25 feet thick immediately below the rhyolite. The tuff resembles that at the base of the rhyolite member in the Steele Hills and Winchester Mountains. The tuff in Kelsey Canyon was assigned to the conglomerate rather than the rhyolite because similar tuff beds are intercalated with the conglomerate lower in the section.

RHYOLITE MEMBER

The principal outcrop area of the rhyolite member is in the Steele Hills and along the west side of the Winchester Mountains. Small outcrops are found 3 miles to the east in the northeastern corner of the Dragoon quadrangle and far to the west in the upper part of Kelsey Canyon. The member may underlie the alluvium of Allen Flat.

The member is characterized by dense pale-red to pale-brown or very light gray rhyolite and trachyte(?). These rocks are resistant to decomposition but disintegrate fairly readily into small fragments. As a result they typically form smooth grassy hills that lack the conspicuous cliffs and ledges of the latite member.

In the Steele Hills-Winchester Mountains area, the lower contact is a channeled surface of unconformity. Th› lowest unit is generally a yellow to bright pink vitric tuff that reaches a thickness of several hundred feet in a pre-rhyolite valley in the SE1/4 sec. 2, T. 14 S., R. 22 E., in the Winchester Mountains. This valley is cut through the latite and basaltic andesite into the Threelinks conglomerate. In the bottom of the valley a porous aggregate of glass shards and pieces of pumice contains many pebbles and boulders of latite and basaltic andesite, some as much as 10 feet in diameter. Higher in the tuff unit the large fragments disappear but sparse 1-inch rock fragments are commonly present. Bedding is evident locally. Apparently the tuff represents several ash falls partly redistributed by running water.

Overlying the porous tuff and in places resting directly on older rocks are abundant dense welded tuffs characterized by scarce small phenocrysts and fragments of sanidine, sodic plagioclase (An_{10-30}), and traces of biotite and quartz in a pale-red aphanitic groundmass. The phenocrysts are smaller (0.25 to 1 mm) and less abundant (generally 3 to 5 percent of the rock) than in the latite member. The groundmass commonly contains small white flattened pumice fragments and less abundant fragments of rhyolite, latite, and basaltic andesite. Small brown streaks and mottles, apparently due to devitrification, are also common in the groundmass. These streaks and the flattened pumice fragments commonly impart a distinct planar structure which parallels the surface on which accumulation took place.

In thin section the original glass shards, although now largely devitrified, are preserved in outline. They are somewhat distorted by compaction but generally less so than in the welded tuff unit in the latite member. Devitrification patterns were developed normal to the shard surfaces, in spherulites, and in lenticular masses about 1 mm thick and 5 or 10 mm across. The lenticular masses have a central axis of cristobalite(?) bordered by long fibers of potassium feldspar standing normal to the axis. Other flat lenticular aggregates consist of sanidine and interstitial and central tridymite or quartz. These masses, which resemble vesicle fillings, have been examined by R. L. Smith, who believed (oral communication, 1955) they represent devitrified pumice fragments, because he has traced pumice fragments into similar aggregates in other areas of welded tuff.

Thin red glassy units were noted at a few places in the Steel Hills and Winchester Mountains as were a few layers of crystal tuff, mixed tuff, and tuff-breccia with abundant lithic fragments several inches in diameter. Lava flows were not positively identified but may be present.

Little or no quartz or tridymite is visible in many specimens, suggesting that the rocks are low-silica rhyolite or trachyte. An excess of silica over the feldspar molecule seems to be invariably present however.

RHYOLITE DIKES

The youngest intrusive rock recognized in the Dragoon quadrangle is rhyolite that forms en echelon dikes in two narrow belts. One belt trends N. 45° W. across the westernmost bedrock outcrop along Highway 86 and is exposed for a length of 2,400 feet (SE¼ sec. 30, T. 16 S., R. 22 E.). The other belt trends N. 40° E. and passes several hundred yards west of Keith Ranch in the Johnny Lyon Hills. It can be followed for more than 3 miles between the alluvial cover on the west and the west-central part of sec. 9, T. 15 S., R. 21 E.

Near Highway 86, the dikes, which have a maximum width of 50 feet, cut the Tertiary aplite and pass beneath alluvium on both sides of the bedrock outcrop.

They strike northwest, dip 45° to 65° SW. and cut the aplite flow structure which has nearly the same strike but dips between vertical and 75° NE.

The dikes in the Johnny Lyon Hills belt are nearly vertical and strike northeast to north. Their thickness increases continuously toward the southwest to a maximum of 100 feet where the last exposed dike passes beneath the alluvium. These dikes cut all bedrock formations, including lamprophyre dikes, and all structural features in their path and are not offset by any later structures. There are a number of apparent offsets in the dikes southwest of Keith Ranch, but the geologic relations in the field suggest that the zones of weakness followed by the dikes had been offset prior to the rhyolite intrusion and that the rhyolite accepted these offsets as it met them. No shearing or other internal evidence of faulting has been recognized in the dikes.

The rhyolite is a light-gray to grayish-red-purple porphyritic-aphanitic rock. It is generally flow banded, and jointed parallel to the flow banding. The composition averages about 10 percent quartz phenocrysts, 10 percent sanidine phenocrysts, and 80 percent groundmass. The quartz phenocrysts range from 0.5 to 3 mm in diameter and show resorption forms. The sanidine phenocrysts are anhedral to subhedral, 1 to 2 mm in diameter, and commonly twinned according to the carlsbad law. Those in the Johnny Lyon Hills dikes are much sericitized and those in the dikes near Highway 86 are replaced in irregular patches by albite. The groundmass in both areas is a microcrystalline intergrowth of quartz, potassium feldspar, and subordinate albite: it is commonly speckled with red iron-oxide dust. The groundmass in the dikes near Highway 86 contains a few small phenocrysts of magnetite (0.1 to 0.2 mm) and scarce aggregates (less than 0.5 mm) of limonite, green biotite, and other secondary minerals that evidently have replaced a primary ferromagnesian silicate. The groundmass in the Johnny Lyon Hills dikes is much sericitized (or kaolinized) and contains some calcite, limonite, and manganese oxide dendrites; no mafic minerals are discernible.

As the rhyolite dikes cut the thrust faults and the Tertiary(?) aplite and lamprophyre, they are younger than any other igneous rocks in the map area, except possibly the Galiuro volcanics. The texture of the dikes indicates a very shallow depth of emplacement. Though no spatial relation of dikes and volcanic rocks is evident, the dikes may have been feeders for flows of the same generation as those to the north.

POST-GALIURO PREALLUVIUM UNCONFORMITY

Tertiary and Quaternary alluvium lies unconformably on the Galiuro volcanics, related(?) rhyolite dikes, and all the older formations. The Galiuro and older formations were faulted and gently folded and then deeply eroded before the alluvium was deposited.

TERTIARY AND QUATERNARY SYSTEMS

ALLUVIUM

Alluvium, with some interbedded lake deposits, covers about half the area mapped (pl. 1). The alluvium fills large intermountain basins. North of the Gunnison Hills, it forms the divide between two major basins for a little more than a mile. On the flanks of the mountains, it is found in the bottom of valleys and in scattered erosional remnants at higher elevations.

As erosion now predominates over deposition in the area, alluvial fans and other constructional topographic features are local and ephemeral features found only where there have been flash floods or other special conditions. Where dissection has been rapid, as along the lower reaches of Tres Alamos Wash and its tributaries, the alluvium commonly forms impressive cliffs as much as 75 feet high. Where erosion has been slower, the alluvium forms smooth rounded surfaces that may reflect the relative resistance of the beds by a rolling steplike form, as in the area of interbedded alluvium and nonresistant lake beds south of the Johnny Lyon Hills. Although the alluvium weathers fairly readily into its constituent fragments, the fragments themselves are generally resistant and in places are too large to be readily transported. Thus the alluvium is more resistant to erosion than formations that break down readily into small particles. The alluvium caps low terraces and buttes in the areas of granitoid igneous rocks and also some conspicuous pediment remnants at the southeast end of the Winchester Mountains.

STRATIGRAPHY

The alluvium lies unconformably on all the other formations. It is made up of at least three parts: (1) older alluvium and lake deposits equivalent to the Gila conglomerate, (2) pediment gravels, and (3) recent stream deposits. The older alluvium underlies the intermountain valleys and consists of a thick faulted and gently folded sequence of fanglomerates and lake beds. The pediment gravels form a thin unconformable mantle which was spread out on erosional surfaces cut on the deformed older alluvium and on prealluvium rocks. The recent stream deposits are along present stream channels cut into all the older rocks. Where outcrops are good, it is generally easy to distinguish the three parts of the alluvium; but where outcrops are poor, as they are at many places that are underlain by alluvium, distinction is not feasible with the data at hand. Therefore all parts are shown as a single formation on the geologic map (pl. 1).

OLDER ALLUVIUM AND LAKE DEPOSITS

The older alluvium ranges from coarse poorly sorted and poorly bedded fanglomerate to fine well-sorted and well-bedded lake deposits. Some parts of the rock are cemented by calcium carbonate, but most of it is poorly consolidated. The sediments are generally coarsest near the present mountains and finest in the centers of the intervening basins, but there are notable exceptions to this generalization and tongues of gravel extend far out into and even across the present basins along old drainage lines.

Regional variations in composition and texture suggest that the older alluvium was derived from two main source areas, one in the Little Dragoons and the other north of the Dragoon quadrangle. The sediments from these centers probably interfinger south of Allen Flat.

The sediments derived from the Little Dragoons are well exposed in the deeply incised arroyos west of the mountains. In this area, the sediments grade from coarse fanglomerate at the mountain front to fine-grained lake beds south of the Johnny Lyon Hills. The lake beds lap up on the south end of the Johnny Lyon Hills, but elsewhere these hills are bordered by coarse alluvium of local derivation.

The fanglomerate near the west side of the Little Dragoons consists of poorly sorted and poorly bedded debris from formations exposed in the mountains. Angular to subangular pebbles, cobbles, and boulders as much as 4 feet in diameter are embedded in a sandy matrix. The rock is commonly cemented by calcium carbonate. Near Tres Alamos Wash this rock contains debris derived from the Johnny Lyon Hills area and also cobbles and boulders of volcanic rocks which have been transported from the source area to the north.

The coarse fanglomerate between the Little Dragoon Mountains and the Johnny Lyon Hills contains some small lenses of sand. To the southwest, the lenses of sand become thicker and more abundant, and the associated conglomerate becomes finer and better sorted. Near the west edge of the quadrangle, these rocks pass laterally into lake beds, which consist predominantly of well-bedded pink and buff sands, silts, and clays. Intercalated beds of pebble conglomerate are common. Scattered gypsum crystals and beds of white calcareous nodules are less common.

According to Heindl (Halpenny and others, 1952, p. 72), there was an old lake basin in the San Pedro valley south of The Narrows, which are several miles west of the Johnny Lyon Hills. The lake beds in the southwestern corner of the Dragoon quadrangle evidently were deposited in this basin.

The older alluvium east of the Little Dragoon Mountains probably represents alluvial fans built out from the Little Dragoons. South of Highway 86 exposures are poor, but available information from drill holes suggests that it is composed largely of debris from the Texas Canyon quartz monzonite. Between Highway 86 and Antelope Tank poorly consolidated fanglomerate is exposed at many places. The fragments range from silt to boulders as much as 5 feet in diameter and include limestone, quartzite, Pinal schist, Texas Canyon quartz monzonite, and copper-stained garnet rock. The fanglomerate is in fault contact with the Glance conglomerate on the west side of the Gunnison Hills; but east of this fault it is in depositional contact on the Glance, in places on the crest and east side of the hills.

The unconformity at the base of the fanglomerate is exposed on the east slope of the Gunnison Hills, several hundred feet north of Highway 86. At this locality, an isolated patch of gravel, which is too small to show on the map, rests on the Glance conglomerate. The unconformity is inclined a few degrees to the east and is nearly parallel to the present surface. Fragments of Barnes conglomerate in the gravel support the interpretation that the source was in the Little Dragoons, for the Barnes occurs there but is not known at any other locality within 25 miles.

Between Antelope Tank and Allen Flat, fanglomerate derived from the Little Dragoons is associated with debris from the Galiuro volcanics, which are exposed to the north and east. The two lithologic types probably interfinger, but the detailed stratigraphic relations are obscured by faults, pediment gravels, recent stream deposits, and soil cover.

Gravel composed largely of limestone of Paleozoic age—and hence regarded as part of an old fan from the Little Dragoons—extends as far east as the Steele Hills, where it forms an isolated erosional remnant resting directly on the rhyolite member of the Galiuro volcanics (pl. 1). Limestone gravel, presumably once continuous with this remnant, crops out about three-quarters of a mile to the northwest and may be traced for more than 3 miles to the north on the west side of the rhyolite outcrops. This gravel has a maximum outcrop width of about half a mile and pinches out near the Willcox-Cascabel road about 2,000 feet southeast of bench mark 4792. It is overlain on the west by alluvium derived from the Galiuro volcanics and is exposed because of late uplift along the Steele Hills-Winchester Mountains axis.

The alluvium derived from the Galiuro volcanics consists of well-bedded and moderately well cemented light-yellow sand and gravel. Rock of this type underlies the eastern half of Allen Flat and extends southeastward to within a mile of Antelope Tank. Its southwest boundary is not exposed. At the south end of the Winchester Mountains, the rock lies unconformably on the rhyolite member of the Galiuro volcanics. It is still well bedded and not noticeably coarser grained near contact, which suggests that it is not of local derivation but was transported a considerable distance from its source.

The well-bedded volcanic alluvium of the eastern part of Allen Flat was not found along the west side. In the upper reaches of Kelsey Canyon and its tributaries the flat is underlain by about 100 feet of pediment(?) gravel apparently of local derivation. Beneath this are older gravels composed largely of fragments of green granitic rock of undetermined source. The granite gravel dips as much as 10° or 20° and is separated by an unconformity from the nearly flat-lying gravel above. A well drilled near the center of Allen Flat, 2 miles north of the Dragoon quadrangle in sec. 28, T. 13 S., R. 22 E., suggests that the granite gravel may lie stratigraphically below the alluvium in the eastern part of the flat. This well, which is 1,180 feet deep, passed through 27 feet of "clay and boulders" then 1,148 feet of "conglomerate" and "sand," and finally 5 feet of "granite conglomerate" (Halpenny and others, 1952, table 16).

PEDIMENT GRAVELS

The pediment gravels form a thin unconformable mantle which was spread out on erosional surfaces cut on the older alluvium and prealluvium rocks. These erosion surfaces and the gravel mantle slope 100 to 400 feet per mile away from the present mountains and are graded to base levels as much as several hundred feet above the present base level. In areas of recent dissection, such as the lower part of Tres Alamos valley, the pediment gravels are being eroded and are preserved only on the divides between arroyos. In those areas not yet affected by recent dissection, such as Allen Flat, the processes of pediment formation are still operating, and new debris is being added at the mountain front to replace that in slow transport downslope.

The pediment gravels are generally less than 25 feet thick but possibly may be as much as 100 feet thick locally. They are made up of materials that were exposed higher in the drainage basin at the time of deposition. Generally the composition is the same as that of the recent stream deposits, but at a few places it is different because of recent stream piracy, erosion of the source area, and perhaps other factors. For example, the highest and oldest pediment gravels southwest of Johnson are composed largely of Paleozoic limestone fragments, whereas the younger pediment gravels and recent stream deposits are composed predominantly of fragments of Precambrian rocks. Pediment gravels made up of fragments of volcanic rock extend more than a mile southwest of Antelope Tank and could not have been emplaced so far south with the topography as it is at present.

RECENT STREAM DEPOSITS

Unconsolidated gravel, sand, and silt are found along the present stream channels. These deposits are negligible in areal extent and quantity compared with the other classes of alluvium. They consist of debris eroded higher in the drainage basin and deposited temporarily in the course of transportation to areas outside of the quadrangle.

THICKNESS

Shafts and borings near the exposures of older rocks in the Little Dragoon Mountains indicate that the alluvium thickens rapidly away from the mountains eastward toward the Gunnison and Steele Hills. Near the Republic mine 3 Coronado Copper and Zinc Co. diamond-drill holes, collaring in alluvium 250 to 700 feet from the nearest exposures of the older rocks, indicate the base of the alluvium is inclined 11° to 20°. The Geological Survey diamond-drill holes at the Standard prospect indicate an inclination of 10° to 12° at that locality. These inclinations, amounting to 930 to 1,910 feet per mile, are equivalent to the mountain slopes of the present time.

No wells in the map area are deep enough to penetrate the alluvium in the centers of the basins. A 656-foot well at Dragoon (Halpenny and others, 1952, table 13) is all in alluvium though less than a mile from exposures of older rock. About 2 miles east of Dragoon, the Southern Pacific Railroad has a well 554 feet deep which, according to the driller's log, is in "solid rock" and "broken rock" below 420 feet. It would appear at first that the alluvium is only 420 feet thick at this locality, but serious doubt of this conclusion is raised by the fact that the same record indicates that "rock" and "broken rock" occur higher in the well alternating with "sand" and "cemented gravel" which are probably alluvium. Another well, on the Thomas Adams Ranch a short distance west of the Gunnison Hills near the center of the NE¼NE¼ sec. 30, T. 15 S., R. 23 E., is 563 feet deep and all in alluvium.

The maximum thickness of alluvium may of course be considerably more than these figures. At least 1,000 feet of alluvium is shown by a well in the San Pedro valley several miles south of the quadrangle boundary in sec. 15, T. 17 S., R. 21 E. (Halpenny and others, 1952, table 13). A well on Allen Flat about 2 miles north of the quadrangle boundary in sec. 28, T. 13 S., R. 22 E., is reported to be 1,180 feet deep, and the log gives no indication that it reached bedrock (Halpenny and others, 1952, table 16).

STRUCTURE

GENERAL FEATURES

The rocks of the Dragoon quadrangle record two major orogenies and at least five lesser disturbances.

The earliest and most intense deformation, evidently the Mazatzal revolution of Wilson (1939, p. 1161), took place in Precambrian time before the Apache group was deposited. During this orogeny the Pinal schist and intrusive rhyolite porphyry were isoclinally folded. The general structural trend is northeastward as it is in many parts of southern Arizona. In the Johnny Lyon Hills and northern part of the Little Dragoon Mountains, the folds are commonly overturned to the northwest and the fold axes are steep. Elsewhere the structure is more erratic and has not been deciphered in detail. Dynamothermal metamorphism was pervasive. Though the thermal effects were of low rank, the dynamic effects were intense and include axial-plane schistosity and lineations, such as boudinage, that parallel the fold axes.

The old structures in the Pinal schist have had little apparent effect in localizing later folds and faults; but major intrusive bodies, which range in age from early Precambrian to Tertiary, are elongated parallel to the old trend (pl. 5).

Minor deformations took place near the close of Precambrian time and at least twice in the interval from Early Permian to Early Cretaceous. The late Precambrian deformation, which is indicated by the relations of the Bolsa quartzite to the Apache group, was very minor and was characterized by regional warps and a few small faults. The post-Permian pre-Cretaceous deformations were considerably more important. The Paleozoic rocks were broken by steep faults, with hundreds of feet of displacement, before the Walnut Gap volcanics were deposited, and faulting occurred again in post-Walnut Gap pre-Bisbee time. The principal fault trends were northeast and east. There was no significant folding but rather an apparently random jostling of fault blocks that did not result in very great structural relief in the Dragoon quadrangle.

Another major orogeny, probably the Laramide revolution of the Rocky Mountain States, took place in Late Cretaceous or early Tertiary time. Rocks older than the Texas Canyon quartz monzonite and the Threelinks conglomerate were folded and thrust faulted. The general structural trend is northwest nearly at right angles to the pre-Apache structures. Four major structural blocks are distinguishable (pl. 5).

Block 1, in the southwestern part of the quadrangle, is characterized by great thrust sheets of Precambrian, Paleozoic, and Mesozoic rocks which have overridden from the southwest. Parts of this block have been displaced by later faults and masked by Cenozoic rocks, but we believe it once included the south tip of the Gunnison Hills east of the Dragoon quadrangle, the north end of the Dragoon Mountains, the Little Dragoons south of the Ceuturion fault and the Lime Peak thrust, and the Johnny Lyon Hills. The block was intruded by the Texas Canyon quartz monzonite, which postdates the thrusts and probably was emplaced at the close of the orogeny. The thrust sheets have been eroded from the exposed parts of the Tungsten King horst on the west side of the Little Dragoons. The postthrust faults that bound this horst are probably Laramide, for one of them (Tungsten King fault) is clearly older than the Tertiary(?) aplite and lamprophyre.

Block 2 is structurally below block 1 and was overridden by it; its dominant structure is a major tilt to the northeast. (See pl. 5.) The Precambrian basement is exposed only along the southwest side of the block. Along the northeast side, at the south end of the Winchester Mountains, the youngest pre-Laramide rocks (Cretaceous(?) sedimentary and volcanic rocks) are exposed and the Precambrian basement is probably many thousands of feet below the surface.

The great tilted block is modified by folds and faults. The folds trend north to northwest. Where the formations of Paleozoic age and the Glance conglomerate are exposed, the folds are broad and open; but where the Morita and Cintura formations are exposed in the Steele Hills, the folds are closed and locally overturned in the northeast. Between the areas of contrasting fold types is the concealed Antelope Tank fault, which was active in late Tertiary or Quaternary time but which probably formed during the Laramide revolution or earlier. Many other faults cut the Cretaceous and older rocks of the block. Thrust faulting was minor and different in direction from that in block 1. The few small thrust plates known in block 2 evidently overrode from the east. Steep faults include a few that trend northwest subparallel to the Antelope Tank fault, and many that trend northeast, east, and north. Some of these faults are pre-Cretaceous and some are post-middle Tertiary, but most of them are probably Laramide. This latter group includes normal faults younger than the folds and thrusts, and possibly some reverse and strike-slip faults formed at the climax of the orogeny.

In block 3, which makes up a small part of the northeastern corner of the Dragoon quadrangle (pl. 5), the Precambrian basement is structurally high and is broken by large faults which trend northwest. Most of this block is concealed by formations of Tertiary and Quaternary ages, but older rocks are exposed in an area 1 by 4 miles extending northwest of the exposure in the Dragoon quadrangle. These rocks consist of Pinal schist and early Precambrian granite, infaulted lenses of limestone of Paleozoic age which trend northwest, and remnants of flat-lying Bolsa quartzite in depositional contact on the granite of Precambrian age. This structurally high, faulted, but apparently unfolded block is separated from block 2 by a zone of thrust(?) and strike-slip(?) faults which trend N. 65° to 70° W. This fault zone, along which the structural relief is very great, parallels the Antelope Tank fault, and we suggest that both are elements of the "Texas lineament," which is a broad and not very well defined zone of faults and other tectonic features that extend west-northwest from southern Texas to the vicinity of Los Angeles, Calif., oblique to the general Cordilleran trend (Hill, 1902, p. 173; Ransome, 1915b, p. 295; Baker, 1934, p. 206–214; Moody and Hill, 1956, p. 1229).

Block 4, as exposed in the western part of the Dragoon quadrangle south of Kelsey Canyon (pl. 5), consists of the Walnut Gap volcanics overturned toward the west. The volcanic rocks are bounded on the east by a zone of thrust faults along which the Precambrian rocks of block 2 have overridden westward. The thrust zone is exposed for only a mile and its relation to other major structures is not known. Parts of block 4 are exposed west of the Dragoon quadrangle between Kelsey Canyon and the Willcox-Cascabel road. These parts, which were not studied in detail, consist of the Walnut Gap volcanics, Glance conglomerate, Morita and Cintura formations, and an overlying thrust plate or plates of limestone of Paleozoic age.

Two episodes of important block faulting and gentle folding postdate the Galiuro volcanics and are largely responsible for the basins and ranges of the present. One of these deformations preceded and the other followed deposition of the older alluvium. The principal features, such as the major synclinal fold in the Galiuro volcanics and the Gunnison Hills and Antelope Tank faults, are shown on the structure map (pl. 5). The most conspicuous folds and faults trend northwest subparallel to the axes of the ranges and basins. Other faults and some associated drag(?) folds trend northeast, north, and west-northwest.

Deformation that postdates the older alluvium is particularly conspicuous near the Gunnison Hills, Steele Hills, and Winchester Mountains. The older alluvium is turned up on the flanks of these ranges and is cut by more than a dozen faults, including the large Gunnison Hills fault. The relations support a statement by Bryan (1926, p. 170) that the mountain blocks in this part of Arizona were pushed up through the less competent valley fill near the end of Tertiary time. No evidence for such late uplift is found near the other mountain blocks in the Dragoon quadrangle, suggesting that these blocks are structurally older features. Possibly they are outlined by block faults which are now concealed by alluvium.

In the following pages each deformation and its effects are discussed in detail. The discussion of the major orogenies is organized on a geographic basis.

PRE-APACHE DEFORMATION

Our objectives in the following discussion are (1) to describe the present structures of the lower Precambrian rocks, (2) to appraise the effects of post-Apache deformations on these structures, and (3) to eliminate the post-Apache effects and restore the structures as they were in pre-Apache time. The Johnny Lyon Hills, in which the objectives are most nearly attainable, are considered first. Then the Little Dragoon Mountains are discussed in more general terms.

JOHNNY LYON HILLS

The Pinal schist and associated rhyolite porphyry sheets near the Johnny Lyon Hills are exposed in an arcuate belt, about 9 miles long and locally nearly 2 miles wide, which trends northeast to north (pl. 5). The schist and porphyry were deformed and regionally metamorphosed in Precambrian time prior to intrusion of the Johnny Lyon granodiorite. During the Laramide revolution, the rocks were intensely redeformed and broken by major thrust faults. The pregranodiorite structures retain a remarkably consistent pattern in spite of later events.

Bedding in the schist strikes northeast; the strike ranges from N. 60° to 80° E. at the south end of the belt to due north at the north end. The beds dip steeply to the southeast and are overturned, for graded bedding is common and nearly everywhere indicates the tops of the beds are to the northwest. Local reversals in the top direction due to minor folds have been noted at a few places.

The emplacement of the Johnny Lyon granodiorite appears to have modified the structural orientation of the schist in the northern part of the belt. Here the strike of bedding and associated schistosity swings from about N. 45° E. at the north edge of the Johnny Lyon Hills to due north at the pinch out south of the Willcox-Cascabel road. This 45° change is accompanied by a 20° or 25° swing, in the same direction, of the overlying unconformable strata. Therefore only the difference between the two changes in bearing (45° minus 20° to 25°) can be attributed, perhaps, to the granodiorite intrusion. Only a slight steepening in dip of the schist accompanies the 45° change in strike.

There is no evidence available from which to determine whether intrusion of the granodiorite caused an overall change in orientation of the schist belt, for no reliable reference structure of known preintrusive orientation has been recognized.

Schistosity is virtually parallel to the bedding in most parts of the schist belt. South of the Johnny Lyon Hills, however, a systematic divergence is evident. The divergence is primarily one of strike, with the bedding striking more easterly (N. 55° to 80° E.) than the schistosity (N. 35° to 60° E.). The angle of divergence appears to increase gradually toward the southeast from almost nothing near the granodiorite to 25° or 30° near the alluvium contact. The divergence generally does not become conspicuous until a point 1,000 to 1,500 feet southeast of the zone of rhyolite porphyry sheets. Both bedding and schistosity generally dip southeast but locally pass through the vertical to dip about 80° NW. These dips are generally within 5° of each other and no consistent directional relation between the two dips could be recognized.

Approximately where the divergence between bedding and schistosity becomes clear, small asymmetric folds in the bedding commonly appear. These folds have axial-plane schistosity (fig. 19) and axes which consistently plunge steeply south or southwest. The amplitudes of the folds are measured in feet or tens of feet. A series of such folds may sometimes be followed obliquely across the schistosity for as much as several hundred feet. The asymmetry of the folds suggests they are drag folds formed by a clockwise couple in which the southeast side of the folded rocks moved southwest relative to opposite movement of the northwest side. Figure 20 is a diagram taken from field sketches and photographs, showing the typical orientation of a series of these folds and the relation of graded bedding in them. Note that the axes of the folds are overturned.

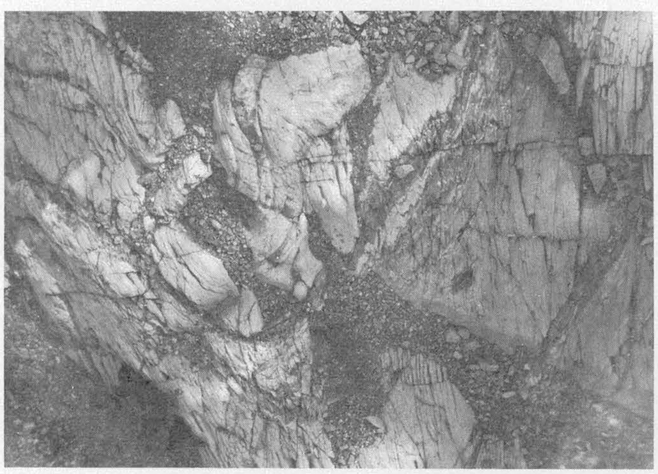

FIGURE 19.—Small fold in interbedded slate and graywacke of the Pinal schist showing the axial plane cleavage. Outcrop several feet long.

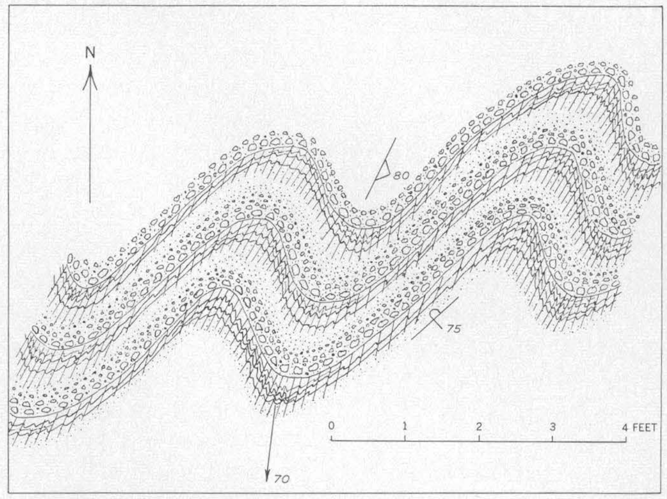

FIGURE 20.—Diagrammatic sketch map of asymmetrical folds in graded beds of the Pinal schist in the Johnny Lyon Hills. The schistosity is parallel to the axial planes but commonly shows a slight radiating pattern in the crests and troughs of folds.

To the southeast of the zone of small asymmetrical folds, somewhat larger and tighter folds appear, but here again northwest-facing beds prevail. The folds are nearly isoclinal and are recognized by local reversals in graded bedding. The reversed beds of some folds can be traced continuously into each other, but commonly the limbs are separated by axial-plane shear surfaces. The axial planes of the folds are a few feet to hundreds of feet apart, and the amplitudes of the folds reach a maximum of many hundreds of feet.

The axial planes of these folds are parallel to the schistosity and dip steeply to the southeast. The axes generally plunge 50° to 80° S. or SW., and graded bedding indicates that the northwest limbs of folds that open to the southwest are overturned, as they are in the more open folds. Again it is clear that the fold axes are overturned.

Lineations in the form of intersections of bedding and schistosity, wrinkling in the schistosity, pencil structure in slate, boudinage structures, and more rarely elongate-porphyroblasts and stretched pebbles have the same orientation as the fold axes that can be observed. Generally two or more of these elements occur together and are parallel. All may be classified as *b*-lineations after the reference axes of Sander (Cloos, 1946, p. 5–6).

Where bedding and schistosity are not parallel, the intersections of these planes have a consistent orientation whether the divergence is local, as in the crest of a small fold, or is persistent for more than a mile of outcrop. This form of lineation is conspicuous in color-banded slate and in interbedded slate and siltstone. At places it is expressed by pencil structure.

Fine-textured wrinkles in the schistosity of slate and phyllite are common. The amplitude and wavelength of the wrinkles are commonly less than 1 mm, but the pervasive strongly oriented pattern generally gives a sharply defined lineation. When found associated with small folds or with boudins, it has a similar orientation (fig. 21). The origin of these wrinkles is not clear.

FIGURE 21.—Phyllite outcrop in the Pinal schist showing the parallelism between small fold axes and wrinkles in the schistosity.

They can be related to intersections of bedding and schistosity at some places but also occur where these planes appear to be parallel. Possibly the crenulations are minute drag folds, but they are too small to establish whether there is any consistent asymmetry.

The most spectacular form of lineation is boudinage, which is best developed in shaly units that contained thin beds of graywacke. In the southern part of the schist belt in the Johnny Lyon Hills, the structure consists of isolated rods or laths of recrystallized muscovite quartzite in a matrix of muscovite-chlorite schist. The rods are elongated in a common direction and have flattened elliptical cross sections. The long and intermediate axes are in the plane of schistosity (fig. 22). Evidently, during tight folding, the coarse-

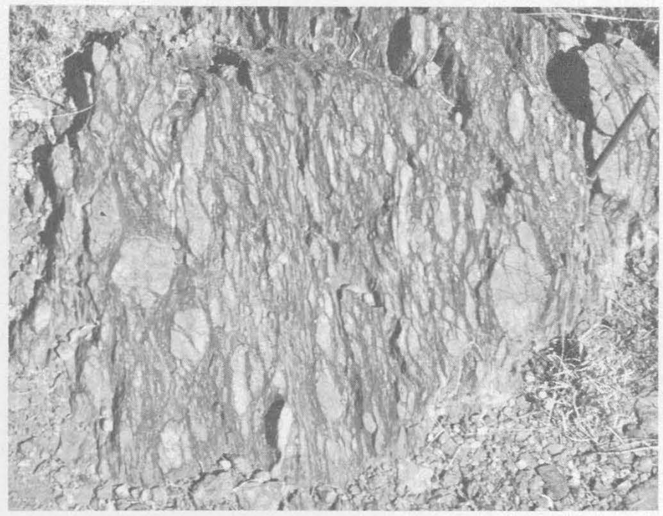

FIGURE 22.—Steeply plunging boudinage in the Pinal schist. Projecting boudins of metagraywacke and the pencil at upper right indicate the direction of plunge. Photograph looking almost directly downward.

grained beds yielded less readily than the associated shaly material, failed in extension, and separated along lines parallel to the fold axes. Various arrested states, from the incipient local thinning or "necking down" or the graywacke bed to actual parting into separate rods or laths, are visible in this area.

At places in the Johnny Lyon Hills area, the pervasive and mutually parallel *b*-lineations are accompanied by other lineations having a different attitude. The commonest of these are nearly horizontal crenulations and tiny close-spaced faults visible in the schistosity planes (fig. 23). The structure, which is due to the intersection of a later subhorizontal fracture cleavage, is best developed near post-Paleozoic thrust faults and is probably of Laramide age.

At a few places south of the Johnny Lyon Hills there coexist two steep lineations, not in agreement and independent of the transverse cleavage. One of these is generally a bedding-schistosity intersection and the other is wrinkling or small-scale drag folding. The divergence between them may be as much as 40°. Whether these are merely statistical variations from the general pattern of agreement of these features due to local conditions, or whether they represent two distinctly different episodes of deformation is not understood.

Lineation attitudes throughout the 9-mile belt of schist are generally consistent as shown in figure 24 which is an equal-area plot of 230 widely spaced observations of all types of lineation mapped, except the nearly horizontal wrinkling related to the late

FIGURE 23.—Phyllite outcrop in the Pinal schist showing a steeply plunging lineation (wrinkling) in the schistosity cut by a younger subhorizontal cleavage and wrinkling. The younger wrinkling is reflecting the light in the lower part of the photograph.

subhorizontal fracture cleavage. A maximum plunging of 56° in a S. 12° W. direction is indicated. The overall consistency is particularly remarkable as the 9-mile belt represents a large body of rock considerably shortened by post-Paleozoic thrust faults.

As the lineations are clearly *b*-lineations with respect to all magnitudes of folding observed in the field and these folds have overturned axes, it would appear by extrapolation that the whole body of rock is now characterized by folds with this unusual form.

The present orientation of the folds is due in part to post-Apache deformation. The northeastern end of the Pinal schist belt in the Johnny Lyon Hills is truncated by the Precambrian unconformity at the base of the Apache group. This unconformity here averages about N. 30° E. in strike and 42° E. in dip, though the gross trend of the contact is more northerly as a result of many right-lateral faults. If the Pinal structures are rotated 42° about a N. 30° W. horizontal axis to restore

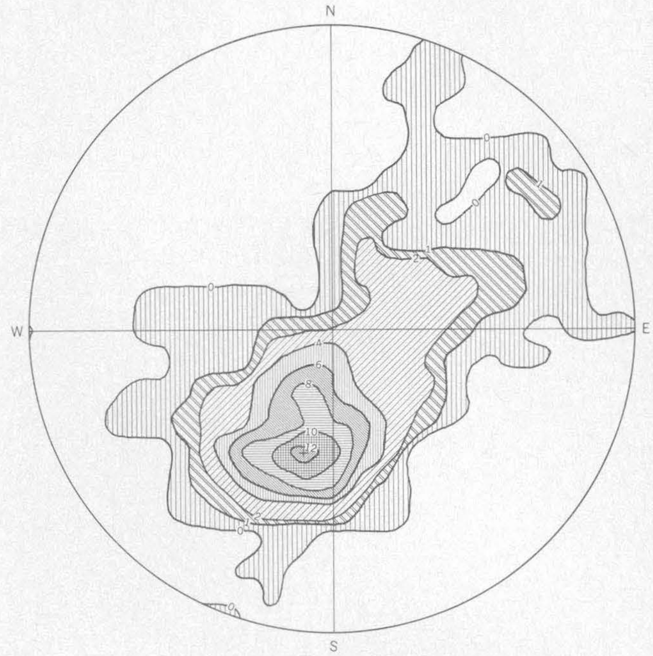

FIGURE 24.—Equal-area contour diagram of 230 lineations in the Pinal schist of the Johnny Lyon Hills. Lower hemisphere projected.

the unconformity to a horizontal position, the average schistosity attitude is changed from N. 45° E., 70° SE. to N. 63° E., 65° SE., and the preferred lineation plunge from S. 12° W., 56° to S. 63° E., 60°. By this restoration, which was made stereographically, the observed folds would still be overturned to the northwest but would now have normal though steeply dipping axes.

The block which must be rotated to include all of the schist is more than 6 miles in a northeast-southwest direction. The uniformity of structural attitudes, particularly the lineations throughout the schist, argues against any lesser size. To rotate a block of such magnitude more than 40° demands much of geologic credibility. It should be pointed out, however, that the required northeast dimension is no greater than that demonstrable in a northwest direction. The pre-Apache unconformity in the Johnny Lyon Hills is exposed for more than 10 miles and has been rotated an average of some 50° (pl. 5). In the Little Dragoon Mountains the pre-Apache unconformity has been thrown into a major transverse and complex buckle, but relatively simple northeastward tilting is again indicated in the Gunnison Hills.

If the large block of the Johnny Lyon Hills was rotated, the southwestern end of the schist belt in the Johnny Lyon Hills was once buried miles deeper than the northeastern end. Such a condition at the time of regional metamorphism might be expected, perhaps, to have produced a higher rank in the nether extremity.

The general uniform rank of metamorphism throughout the belt does not confirm this.

In summary, the pre-Apache deformation in the Johnny Lyon Hills area overturned a thick section of the Pinal schist toward the northwest and locally formed small folds overturned in the same direction. The shear couple indicated by the overfolding appears to have had a considerable lateral component for it yielded folds with steep and consistent plunge, about 60° SE. according to our restoration. The only recognized faults of this age are shear planes apparently of small displacement that break the crests of some of the isoclinal folds. It is possible that major strike faults are present, for such faults are to be expected in deformed zones of the type found here. Unfortunately, there are no stratigraphic markers by means of which such faults might be recognized. The continuity of the zone of rhyolite porphyry sheets argues strongly against important transverse faults of pre-Apache age (pl. 5). Earlier Precambrian but postgranodiorite shear zones that trend north and that were loci of alteration have been noted on page 30.

LITTLE DRAGOON MOUNTAINS

Schistosity and relict bedding in the Pinal schist in the Little Dragoon Mountains are virtually parallel and generally strike northeast as in the Johnny Lyon Hills, but they lack the consistent southeast dip which characterizes the Johnny Lyon Hills area. Lineations are also less consistent in attitude. Graded bedding from which we could determine top directions in the schist is abundant north and northeast of Lime Peak but scarce in other parts of the mountains. Everywhere the data available indicate that the top of the beds is dominantly to the northwest but is reversed on many isoclinal folds.

On the basis of determinations of tops of graded beds, Anderson (1951, p. 1334) suggested that the large mass of metabasalt northeast of Lime Peak is older than the adjacent sericite schist and metagraywacke (pl. 1). We could not confirm this suggestion which is obviously important to correct interpretation of the structure. It is true that graded beds to be seen very near the basalt generally face outward, but there are many reversals on small folds, and the basalt is in an area of generally northwestward-facing beds. The small folds die out along the strike southwest of the basalt and therefore were probably formed because the basalt was a competent rock and the less competent sedimentary rock was crumpled around it. Although many details of structure are obscure, we believe the the metabasalt to be intercalated with the enclosing metasedimentary rock. If the metabasalt mass represents flows—which cannot be regarded as established—its stratigraphic relations are probably like those of the small flows south of the latitude of Lime Peak, though its stratigraphic horizon is probably different.

The metarhyolite lenses in a zone which passes several thousand feet southeast of the large mass of metabasalt certainly have their tops to the northwest as shown by flow-breccia tops and graded bedding in the enclosing metasedimentary rock (pl. 1). As suggested by Anderson (1951, p. 1335), the rhyolite lenses probably represent parts of a single flow which has been severed and pulled apart. In every respect except size, the lenses are similar to boudins in the metasedimentary rock. If they are large boudins, a lengthening of about 15 percent perpendicular to the direction of principal deformational movement is indicated.

The metagraywacke mapped northwest of Lime Peak also has its top to the northwest if the few determinations of tops we have in this area are representative (pl. 1). Graded beds that could be interpreted with assurance were not found within the metagraywacke masses and are scarce in the immediately adjacent rock.

A few feet to 1,500 feet north of the eastern half of the largest mass of metagraywacke, the schistosity and bedding are overturned in several narrow belts subparallel to the north contact of the metagraywacke. Individual belts are several hundred feet wide and can be traced for as much as 3,000 feet along the strike. The western belts trend N. 75° E. and are distinctly oblique to the general strike of the schist, whereas the eastern belts trend N. 50° E. and are almost parallel to the general strike of the schist. The regional schistosity here dips 75° NW. but near the center of each belt dips 20° to 55° SE. Toward both sides the schistosity steepens, passes through the vertical, and assumes the regional northwest dip. The form of these folds suggests that they could be due to drag on thrust faults which dip south-southeast, but fault movement could nowhere be confirmed. The folds clearly postdate the schistosity and we suggest that they may be of Laramide origin, perhaps related in some unknown way to the Lime Peak thrust (p. 106).

The sericite schist a mile or two north and northwest of Lime Peak is in two masses, both of which are closely folded (pl. 1). The northeastern mass is in several isoclinal folds overturned to the northwest, as evidenced by graded bedding in the enclosing sericite schist-metagraywacke member. The two large prongs, as well as some of the smaller prongs, of the latter member are anticlines. The large folds, which can be traced for 1 to 1½ miles along the strike, have wavelengths of 1,000 to 1,500 feet and amplitudes as much as several thousand feet. They are characterized by axial-plane schistosity and southward-plunging lineation, exactly as are the folds in the Johnny Lyon Hills.

In the narrow belt between the northeastern mass of sericite schist and the rhyolite porphyry to the west, sparse graded bedding indicates that the top of the beds is to the northwest, a direction opposite the one to be expected from the fold pattern to the south. To explain the relation one must infer either that part of the fold has been sheared off or that the sericite schist wedges out to the southwest. The former alternative is inferred on the maps (pls. 1, 5) because the proximity and structure of the southwestern mass of sericite schist suggest that the two masses may be displaced segments of a once continuous mass.

The northeastern tip of the western mass is a syncline which is sharply overturned to the northwest like the folds in the eastern mass. To the west, however, the overturned southeast limb and associated schistosity steepen, pass through the vertical, and dip steeply northwest (pl. 1). The northwest limb and associated schistosity have the same general attitude throughout. Within the western mass of sericite schist the dip of the schistosity changes abruptly from 30° SE. in the north limb to 80° NW. in the south limb. One possible interpretation of the relation is that the inferred fault passes through the western sericite schist mass as shown on plate 5 and had a left-lateral offset of ½ to 1 mile.

The fault offset could be due in part to Laramide movement. The inferred fault is the projection of a steep Laramide fault which offsets the pre-Apache unconformity 1,600 feet in a right-lateral sense. This fault probably had a major vertical component of movement as did most of the steep Laramide faults whose slip direction has been determined. Hence left-lateral displacement of folds in the Pinal schist is to be expected as these folds plunge south whereas the pre-Apache unconformity dips north. If dip-slip movement on the fault is assumed, the Laramide offset of folds in the schist was about a thousand feet left lateral. As the total inferred offset in the schist is ½ to 1 mile, most of the fault movement must be assigned to older Precambrian time.

The large masses of rhyolite porphyry northwest of the belt of sericite schist were responsible for much of the complex structure around them. The competent porphyry evidently formed buttresses around which the less competent Pinal schist was molded by folding, stretching, and plastic flow (pl. 1). In the quadrant of the porphyry area that is exposed, the regional trend of bedding and schistosity is deflected about 60°. In narrow septa of schist between the porphyry masses the deflection is as much as 140°. These deflections and associated boudinage are certainly of older Precambrian origin, for no disturbance associated with the porphyry is evident in the Apache group which overlies the porphyry unconformably. Though some structural disturbance may have taken place during intrusion of the porphyry, most of it was during the older Precambrian deformation inasmuch as the regional schistosity is deflected along with the beds and the margins of the porphyry masses are as schistose as the intruded rock.

A large northwestward buckle in bedding and schistosity southeast of Lime Peak seems incompatible with structure known to be of older Precambrian origin. The most tightly compressed part of this fold is defined approximately by metabasalt flows shown on the maps (pls. 1, 5). Scarce and obscure graded bedding and local amygdaloidal and fragmental tops(?) of the flows indicate that the fold is an anticline plunging to the northwest. The base of the anticline, measured in a northeast direction parallel to the regional strike of the schist, is about a mile across, and the northwest dimension is about a mile also. We suggest that the anticline is of Laramide origin and perhaps is a large drag fold beneath the Lime Peak thrust plate which overrode this area toward the northeast (p. 106).

Near Johnson and farther south, the strike of the schistosity ranges from north to east subparallel to exposed contacts of the Texas Canyon quartz monzonite (pls. 1, 6, fig. 38). As pointed out previously (p. 79), we believe that forceful intrusion during an early stage of emplacement of the quartz monzonite shouldered aside the schist. The effects of such shouldering action have not been recognized in the schist where the edge of the stock is parallel to the general northeast structural trend of older Precambrian origin.

The structure of the schist south and southwest of Lime Peak has defied detailed interpretation. The regional northeast trend is recognizable and an ill-defined zone of metabasalt flows suggests a general continuity of structure (pl. 5). The erratic variations in the attitude of bedding, schistosity, and lineations that occur are not understood. Abrupt changes in attitude of one or more of these elements along some of the Laramide faults are helpful in tracing these faults through the schist.

LATE PRECAMBRIAN DEFORMATION

Gentle warping and probably very minor faulting occurred in post-Apache pre-Bolsa time. The evidence for this deformation is very largely stratigraphic and is discussed in the section on the pre-Bolsa unconformity. The character of the deformation is illustrated in figure 6. The fault shown in section *B–B′* of this illustration is inferred to explain the stratigraphic relations. A small monoclinal fold would explain the relations as well.

A small pre-Bolsa fault is suggested by the map relations west of the South Camp fault in the NW¼ sec. 25, T. 15 S., R. 21 E. The Pioneer shale and the Bolsa quartzite are here cut by two small faults. The principal movement on both faults was post-Bolsa, but there appears to have been pre-Bolsa movement on the western fault, for on the downthrown side of this fault about 65 feet of diabase of Precambrian age is preserved below the Bolsa, whereas on the upthrown side no diabase occurs and the Pioneer is somewhat reduced in thickness. The relations suggest that the late Precambrian rocks were faulted, beveled by the pre-Bolsa unconformity, and faulted again by renewed movement. If this interpretation is correct, the stratigraphic displacement in pre-Bolsa time was about 130 feet.

If other late Precambrian structures are present in the Dragoon quadrangle they are indistinguishable from those of later origin. As Precambrian structures would probably be recognizable in the extensive areas in which both late Precambrian and Paleozoic rocks are exposed, we must conclude that the deformation was very minor and of negligible importance in the structural development.

POST-PALEOZOIC–PRE-CRETACEOUS DEFORMATIONS

Regional deformation in the interval between the Permian and Cretaceous periods is indicated by the great thickness and coarse texture of the Glance conglomerate and by the diversity of formations from which its boulders were derived. The structural development during this interval can be determined only where unfaulted contacts between the formations of Paleozoic and Mesozoic ages may be observed. Unfortunately these critical contacts are exposed at few places in the Dragoon quadrangle. In much of the quadrangle it is impossible to distinguish post-Paleozoic pre-Cretaceous structures from those of post-Cretaceous age.

In the Gunnison Hills east of Walnut Gap, the Mesozoic rocks are in depositional contact on Paleozoic rocks for about 1½ miles. The relations require two deformations between Paleozoic and Cretaceous time, one older and one younger than the Walnut Gap volcanics. Both deformations involved important faulting but apparently little folding, for the angular discordance between formations of Paleozoic and Mesozoic ages is slight.

Pre-Walnut Gap faulting is shown by geologic relations on the west side of the large outcrop of the volcanic rocks about 1½ miles south of Highway 86. Here the volcanic rocks truncate a northeastward-trending fault concealed by the narrow tongue of alluvium shown on the geologic map (pl. 1). The relations of the Scherrer-Concha contact on the two sides of this fault show that the south side was downthrown, with a horizontal offset of about 800 feet and a vertical separation of about 475 feet. The base of the volcanic rocks truncates the fault without being offset; it lies on beds about 250 feet above the Scherrer-Concha contact on the downthrown side and on beds about 200 feet below this contact on the upthrown side.

Post-Walnut Gap and pre-Glance faulting is indicated by geologic relations along the north side of the same volcanic outcrop. Here a normal fault zone, with an approximate attitude of N. 55° E. 40° S., offsets the base of the Concha limestone 1,800 feet, indicating a stratigraphic throw of 1,000 to 1,100 feet. The Walnut Gap volcanics are confined to the downthrown side and must be cut off by the fault, though the fault is not exposed in contact with the volcanic rocks. The same fault offsets the base of the Glance conglomerate about 750 feet, indicating a stratigraphic throw of 400 to 450 feet. These relations indicate that the greatest movement on the fault (throw about 600 ft) was post-Walnut Gap and pre-Glance, and renewed movement (throw about 400 ft) occurred in post-Glance time.

A short distance north of the locality just described, there are definitely pre-Glance faults that trend west to N. 75° W., and one of these offsets a small normal fault that strikes N. 15° to 30° E. and dips about 70° SE. The map relations (pl. 1) suggest that other generally east-west and northeast faults in this area had part of their movement in pre-Glance time. All these faults with determinable attitude are normal faults. Some of the northeast faults, like the small one mentioned above, have virtually the same attitude as the abundant Northeasters in the Johnson Camp mining area. The east-west faults also have their counterparts elsewhere in the quadrangle.

In summary, it may be said that block faulting of significant magnitude was repeated and possibly widespread in the Dragoon quadrangle during the post-Paleozoic pre-Cretaceous interval. Sets of faults trending northeast and east were formed. The structural relief that resulted probably was small as the Lower Cretaceous rocks are not known to rest on formations below the Naco group, and thick Paleozoic sections are exposed over a considerable part of the quadrangle. South of the quadrangle, in the Dragoon and Mule Mountains, post-Paleozoic pre-Cretaceous granite was intruded, and some pre-Cretaceous faults have been interpreted as thrusts (Gilluly, 1956, pl. 6, section *I–I'*). The regional trend of the deformation is not known. In the Dragoon Mountains, Lower Cretaceous rocks lie on upper Paleozoic rocks wherever the base is exposed, but major structural relief is evident in the Mule Mountains and in the northern part of the Dos Cabezas range, where Lower Cretaceous rocks are in depositional contact on the Pinal schist as well as younger rocks. The relations in the Mule Mountains are described by Ransome (1904 p. 57–63) and Gilluly (1956, p. 67); those in the Dos Cabezas are shown on the geologic map of Arizona and have been checked by our reconnaissance.

LATE CRETACEOUS OR EARLY TERTIARY DEFORMATION

A major orogeny, regarded as part of the Laramide revolution of the Rocky Mountain region, has affected the Mesozoic and older rocks but not those of Tertiary age. Old faults were reactivated and modified and new folds and thrust faults were formed on a major scale. Post-Paleozoic structures that cannot be otherwise dated are discussed in connection with this orogeny. The possibility that some of these structures were of earlier origin should be kept constantly in mind.

DRAGOON MOUNTAINS

The north end of the Dragoon Mountains is part of the southern zone of post-Early Cretaceous thrust faults (pl. 5, block 1) and is characterized by tight folds that trend northwest and by steep thrust faults that parallel the strike. In the small part of the range within the Dragoon quadrangle, the general structural relations suggest that the steep-dipping to overturned west limbs of two synclines have been brought together by thrusting (pl. 2, section *Q–Q′*).

Along the west side of the range, the Pinal schist is exposed in fault contact with gneissic granite which appears to have ridden eastward over the schist on a small reverse fault which dips 62° W. The Bolsa quartzite, with depositional contact on the schist, stands vertical and faces east. Formations stratigraphically above the Bolsa are intensely compressed and some are repeated in a zone half a mile wide between the Bolsa outcrop and Wood Canyon. Plastic deformation, indicated by cleavage in the shaly beds and by flowage and recrystallization phenomena in the limestone, is more evident in this zone than anywhere else in the quadrangle. The Ligier marble quarries are located in the zone. The pervasive recrystallization has masked some of the distinguishing features of the formations so that the mapping is necessarily less reliable than in most other parts of the quadrangle. Nevertheless, we believe the general relations of the formations to be as depicted on the map. As some features had to be omitted because of the scale of the map, the actual relations are more complex than shown.

In a belt about half a mile wide immediately east of the Bolsa outcrop, the Abrigo, Martin, Escabrosa, Horquilla, and Earp formations crop out in their proper stratigraphic sequence, although the total thickness is much reduced and several formations are sheared out locally. Minor folds plunging about 20° S. were noted at several places. At some places the contacts between formations are clearly faults, but elsewhere the nature of the contacts is obscure and our interpretation of them as steep thrusts is largely subjective.

Near the divide on the west side of Wood Canyon the Earp formation is in fault contact with the Horquilla limestone and a narrow intervening wedge of Glance conglomerate. Both contacts of the Glance wedge are regarded as faults because in the north point of the wedge the Glance is in apparent depositional contact on the Epitaph dolomite. The exposed area of Epitaph is so small that it is not shown on the geologic map (pl. 1). The fault that bounds the Glance wedge on the east is the western of the two thrusts on the structure map (pl. 5). The formations west of this thrust are in proper stratigraphic sequence.

On the west side of Wood Canyon, the Horquilla limestone has been thrust over a block consisting of Epitaph dolomite overlain unconformably by the Glance conglomerate. The Epitaph and Glance block and the Horquilla limestone, together, are only about a thousand feet wide and are cut off on the east by another fault which is concealed beneath the alluvium in the bottom of the canyon. Exposures east of the quadrangle boundary show this fault trends about N. 40° W., parallel to the lower part of the canyon. It must be of considerable magnitude for it brings Glance conglomerate on the west in contact with Horquilla limestone on the east. It is the lowest fault shown on section *Q–Q′* (pl. 2) and the eastern of the two thrusts on the structure map (pl. 5).

The Horquilla limestone beneath this thrust is overturned toward the east. Reconnaissance east of the Dragoon quadrangle boundary indicates that the Horquilla is in the west limb of a large syncline which involves the overlying formations of Paleozoic age and the Bisbee group.

On the east side of Wood Canyon near its mouth, the overturned Horquilla limestone of the syncline is cut off by a northeastward-trending tear(?) fault (pl. 1). North of the tear(?) fault the Horquilla limestone, Earp formation, and Colina limestone are all exposed in a faulted and closely folded block. In the western part of the block, the Horquilla limestone and the Earp formation are exposed, the latter in the core of a syncline with axial plane dipping about 60° W. Slightly farther east, but separated from the syncline by a tongue of alluvium that is believed to conceal a thrust fault, parts of the Earp formation and Colina limestone crop out in an overturned position with their top facing east.

The major structural features of the Dragoon Mountains as we have been able to determine them—dynamic thinning of formations, flowage and recrystallization phenomena, repetition of units by strike faults, structural asymmetry, and overturning to the east-northeast—suggest intense deformational movements toward the east-northeast. This conclusion is in general agreement with those of Gilluly (1956, p. 133) for the adjacent part of the range which he described as "a succession of closely folded rocks, cut by folded thrusts, steep reverse faults, and flat thrust faults, the whole indicating overriding from the west."

LITTLE DRAGOON MOUNTAINS

ZONE OF THRUSTS SOUTHEAST OF THE TEXAS CANYON STOCK

The structures exposed on the southeast flank of the Little Dragoons between the Texas Canyon quartz monzonite on the west and the blanketing alluvium on the east have a general resemblance to those in the main Dragoon Mountains though they have a more westerly trend. They are regarded as part of the same belt of deformation (pl. 5, block 1). The Texas Canyon quartz monzonite is younger than the structures and cuts them off on the west and probably also in depth. Contact metamorphism, everywhere evident in the form of recrystallization and mineralogical reconstitution, has healed fault zones and destroyed some primary sedimentary features such as fossils and the original color and texture of beds. Thus many of the ordinary criteria for structural interpretation are lacking, and some doubt must remain even in the recognition of formations. Nevertheless, the main features of the structure and distribution of formations are decipherable with considerable assurance.

The intensely deformed zone is made up of northwestward-trending belts that consist, from southwest to northeast, of Pinal schist, Morita and Cintura formations, Paleozoic rocks, and once again the Pinal schist (pls. 1, 5). The Pinal schist on the southwestern side of the zone is exposed in several roof pendants southeast of Adams Ranch. It has the northeastward-trending structure so characteristic of the lower Precambrian rocks. Its contact with the Morita and Cintura formations, exposed at only one place, is a northwestward-trending fault which we interpret as a major thrust fault on which the Pinal schist has overridden.

The Morita and Cintura formations, which crop out in a belt 1¼ miles wide, are much metamorphosed, but bedding is well preserved. The beds strike northwest and dip 30° to 60° SW. except in the southern outcrops where they dip 60° to 85° NE. No basis for distinguishing tops from bottoms of beds was found, and the relation of the opposite-dipping segments is obscure.

The Morita and Cintura formations are in fault contact with limestone of Paleozoic age along the northeast side. At places the fault is actually a zone several hundred feet wide in which there is dynamic interlayering and interfingering of formations. These complications are on too small a scale to be shown on the geologic map except for a large wedge of the Earp formation adjacent to the quartz monzonite, which cuts off the fault zone on the northwest. The bedding attitude in this wedge is transverse to the fault zone and to the bedding attitude of the formations on the two sides. This relation suggests either lateral or thrust movement on the fault. We believe the fault is a southwestward-dipping thrust (pl. 2, section *P–P′*) because of shearing and drag effects. The Morita and Cintura formations on the southwest have a gneissic foliation that strikes parallel to the fault and dips 25° to 60° SW. This foliation is probably due to Laramide shearing followed by hornfelsing action of the quartz monzonite. In parts of the fault zone, beds of the Horquilla limestone have either flowed or been dragged into parallelism with the foliation in the Morita and Cintura formations, though a short distance away they dip in the opposite direction.

Formations of Paleozoic age are exposed between the fault just described and the Centurion fault 2 miles to the northeast (pl. 5). The beds strike northwest nearly parallel to the bounding faults and dip toward the center of the belt on both sides. The distribution of formations confirms a major syncline in the center of the belt (pl. 2, section *P–P′*). The syncline is tight, upright, and asymmetric. Its axial plane dips about 75° SW. Both limbs are cut by strike faults which dip 70° to 80° SW. at the few places where dips could be measured. Several large faults of this type in the southwestern part of the belt and a concealed fault that must cut the north limb of the syncline are interpreted tentatively as steep thrust faults to conform to what seems to be the fundamental structural pattern in the belt of thrusts (pl. 5, block 1). The relation of these structures to those in the Dragoon Mountains is not known; we tentatively correlate the syncline with the one below the lowest thrust in section *Q–Q′* (pl. 2).

The Paleozoic rocks are cut off by the Centurion fault, which strikes N. 70° W. and dips 70° SW. The Centurion mine workings (pl. 12) explore this fault to a depth of 520 feet, where the fault brings Escabrosa and Black Prince limestones in the hanging wall against Pinal schist in the footwall. This relation of formations on the two sides suggests it is a normal fault, as do slickensiding and drag on small parallel faults exposed in the mine. The relations are not as simple as would appear, however, as the Centurion fault has had at least two periods of movement. Its main movement was prequartz monzonite, for the main intrusive contact is not offset and a tongue of quartz monzonite was intruded along the fault (pl. 2, section *P–P′*). Minor postquartz-monzonite movement is indicated by shearing and silicification of the intrusive tongue. The minor normal faulting in the mine probably took place during this later period of movement for aplite dikes and associated quartz veins are offset. The earlier movements may well have been of the thrust type.

About 2 miles west of Dragoon a tear(?) fault that strikes about N. 30° E. and dips 70° NW. is exposed at intervals for a little more than a mile in the Paleozoic rocks and Morita and Cintura formations (pl. 1). This fault cuts and offsets all the northwestward-trending faults in its path and is marked at one place by a silicified zone but no apparent offset in the quartz monzonite. The offset of the northwestward-trending faults is uniformly right lateral and reaches a maximum of 400 feet.

LIME PEAK-SHEEP BASIN AREA

By the name "Lime Peak-Sheep Basin area" we mean the part of the belt of thrusts (pl. 5, block 1) bounded on the southeast by the Texas Canyon quartz monzonite and Tertiary(?) aplite, on the northeast and north by the Lime Peak thrust, and on the west by the Tungsten King fault.

The relation of structural features in this area to those just described is obscured by the Texas Canyon stock, but roof pendants suggest that outcrops of the Morita and Cintura formations in lower Sheep Basin are part of the same structural unit as those southeast of the stock (pl. 1). If this correlation is correct, a pile of thrust plates in lower Sheep Basin occupies the same structural level as the Pinal schist outcrops southeast of Adams Ranch. The thrust plates in the pile are thin, nearly horizontal, and composed of Paleozoic rocks except for the lowest plate at the north end of the pile which contains the Pioneer shale and some of the Pinal schist below it. These flat plates have completely overridden the Morita and Cintura formations and at the north end rest on the Pinal schist (pl. 2, section *N–N′*).

The rocks between the thrust pile in lower Sheep Basin and the Lime Peak thrust occupy a lower structural zone than the Morita and Cintura formations and thus occupy the same structural level as the Paleozoic rocks south of the Centurion fault. A large post-Paleozoic syncline is present in both areas, but the basement rocks stand much higher in the Lime Peak-Sheep Basin area. The fault pattern is different and suggests that the thrusts flattened near the top of the basement rocks.

The structure of the Lime Peak-Sheep Basin area, illustrated in sections *M–M′*, *N–N′*, and *O–O′* (pl. 2), includes post-Paleozoic folds, horizontal to moderately inclined thrust faults and transverse strike-slip faults which suggest principal deformational movement toward the east or northeast, and later normal faults which have dislocated the folds and thrusts. Some details of the larger structures will be given in the following paragraphs, beginning at the north or structurally lowest part.

LIME PEAK THRUST

In the Lime Peak area an open syncline of late Precambrian and Paleozoic rocks has an arcuate axis plunging gently to the north (pl. 5). The syncline has been thrust into its present position along a southwestward-dipping fault, the Lime Peak thrust, which cuts off the syncline and brings the formations of Paleozoic age into contact with Pinal schist on the north slope of the peak. Fault slices of Bolsa quartzite, one large enough to show on the geologic map, are found at several places in the fault zone. In the saddle east of the peak, the fault splits: the main branch enters the Pinal schist, and lesser branches cut the Paleozoic rocks. Overriding of upper formations over lower formations along the lessor branches has thinned the Paleozoic section markedly.

Two isolated erosional remnants or klippen of the Lime Peak thrust plate are preserved on top of the ridge connecting Lime and Johnson Peaks. They lie one-quarter to a little more than three-quarters of a mile from the nearest exposure of the main part of the plate. Their preservation is due in part to topography and in part to local changes in attitude of the fault surface. The thrust beneath the klippen dips at angles less than 20° and is in part horizontal, judging from its trace on the topography. Overriding of upper stratigraphic units over lower, evident in the main part of the plate nearby, is also evident here. The klippe nearest Lime Peak is mostly Escabrosa limestone but has mappable slices of the Bolsa, Abrigo, and Martin formations at its base. The klippe farthest from Lime Peak, which represents a more distal part of the plate, is entirely Escabrosa limestone.

The Lime Peak thrust is difficult to trace where both its walls are Pinal schist because of the general lack of markers in the schist. The position shown in the map is tentative and the structural interpretations of this part of the thrust are somewhat subjective.

On the northwest flank of Lime Peak the thrust appears to split: A minor(?) branch turns southward through the Bolsa quartzite and passes into a northeastward-trending tear(?) fault in the Pinal schist; the main(?) branch passes westward into the schist and probably continues to the Tungsten King fault which cuts it off (pl. 5). Our interpretation of its position is based on an isolated fault block of Pioneer shale and Bolsa quartzite in the schist ¾ mile northwest of Lime Peak and a moderately well exposed zone of shearing and local structural discontinuity in the schist ¼ to ¾ mile farther west. In the uplifted block west of the Tungsten King fault, the thrust has not been recognized and is presumed to have been eroded away.

From Lime Peak west the metarhyolite and metagraywacke units in the Pinal schist of the overridden block maintain their regional northeast trend beneath the thrust plate. Indeed they appear in the plate itself with no apparent offset if the course of the main branch of the thrust west of the peak has been interpreted correctly (pl. 5). To obtain this relation, the net displacement on the thrust must have been about N. 45° E. parallel to the general strike of the schist. North of this segment of the thrust are zones of overturning in the Pinal schist which could be of Laramide origin (p. 101).

The location of the Lime Peak thrust in the basement rocks east and southeast of Lime Peak is indicated by the presence of two small and apparently overridden masses of Pioneer shale in the footwall block. Bedding and schistosity in the Pinal schist east of this segment of the fault have been buckled into a local anticline which has a northward-trending axis, possibly as a result of crowding by the thrust plate (p. 102).

Farther south the position of the thrust is uncertain. Our interpretation, namely that the southern segment lies far to the west because of a wrench fault related to the thrusting, is based largely on a marked change in attitude of the principal lineation in the schist at the location of the inferred western segment (pl. 1). This permits interpretation of the syncline on Lime Peak as a displaced segment of a similar syncline in Sheep Basin (pl. 5).

HUGHES CANYON FAULT

About a quarter of a mile north of the tear fault that separates the two segments of the Lime Peak thrust, a nearly parallel fault trends east in Hughes Canyon and can be traced for about 2 miles. It is a steep normal fault with downthrow to the north. It cuts the Lime Peak syncline and brings the Abrigo and underlying formations against the Pinal schist. A part of the syncline is preserved on the upthrown southern side in the form of an isolated patch of Pioneer shale. The general relations indicate that the fault here has a throw of several hundred feet with little if any lateral movement. Thus it is considered fundamentally different from the tear fault to the south. The Hughes Canyon fault is clearly younger than the thrusting for it cuts and offsets the Tungsten King fault, itself postthrust. The other small faults in the northern part of the Lime Peak thrust plate require no special comment as they conform to the general fault pattern in the northeastern part of the range (p. 112).

SHEEP BASIN SYNCLINE

A mile or two south of Lime Peak on the west of Sheep Basin there are identifiable remnants of a large complexly faulted syncline in the Apache and Paleozoic rocks. The syncline plunges north, in the same direction as the syncline on Lime Peak, and we suggest tentatively that the two synclines represent displaced segments of the same fold (pl. 5). According to this interpretation, the segment on Lime Peak was torn off and carried eastward and upward along a right-lateral strike-slip fault. Movement on this fault must have followed the principal movement on the Lime Peak thrust, for the fault is offset as much as the syncline.

The Sheep Basin syncline itself is a complex structure. The west limb dips in general 60° to 80° E. and is relatively little modified by minor folds and faults. Most of the east limb is faulted off but the parts preserved dip in general 25° to 50° W. and display minor folds trending north and northeast. The minor folds that trend north probably formed at the time of thrusting and closing of the major fold. The minor folds that trend northeast are all within half a mile of the Texas Canyon quartz monzonite and are attributed to lateral shove during the early stage of emplacement of that body. There are many faults, some older or contemporaneous with the thrusting and others younger. Many of the larger faults appear to be postthrust normal faults and are so interpreted on sections *M–M′* and *N–N′* (pl. 2). The largest of these faults emerges from beneath the alluvium on the southeast side of the syncline. It trends north cutting off the modified east limb and then curves west across the axis. The dip appears to be steep to the west in the northward-trending part but flattens in the westward-trending part, judging by the trace on the topography. The relative position of formations on the two sides of the fault indicates that the south or hanging-wall side has been downthrown 1,500 to 2,000 feet with little lateral displacement. This normal fault, like the one in Hughes Canyon, offsets the Tungsten King fault and hence is postthrust.

Some indication of the character of the eroded southern extension of the Sheep Basin syncline is provided by a small exposure of Pioneer shale in a

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down-faulted block 1,000 feet south of the main remnant of the fold. The Pioneer in the down-faulted block is in a syncline with its axis nearly horizontal and directly on line with the northward-plunging axis of the main remnant. It is strongly asymmetric and overturned toward the east. The upright east limb dips about 45° W., whereas the west limb is slightly overturned to dip 80° to 85° W.

THRUST PLATES IN THE LOWER PART OF SHEEP BASIN

On the ridge crest half a mile west of the locality just described, a small remnant of a higher thrust plate is preserved immediately east (on the downthrown side) of the Tungsten King fault (pl. 5). The remnant lies on the Pinal schist and consists of schist overlain in depositional contact by part of the Apache group cut by diabase sills. The upper Precambrian rocks dip 60° to 65° NE. and are cut off on the north and east sides by a thrust dipping 32° SW. at the single place where its attitude could be measured. Northeastward-trending tear faults cut the plate but not the thrust below it, and two small northward-trending faults offset the thrust several hundred feet. The thrust is cut off by the Tungsten King fault at the north and presumably at the south also though its position in the schist south of the upper Precambrian rocks could not be determined.

In the lower part of Sheep Basin, a pile of thrust plates of upper Precambrian and Paleozoic rocks is exposed east of the Tungsten King fault. The pile is intruded and cut off on the east by the Texas Canyon quartz monzonite and tertiary(?) aplite. Aplite dikes cut many of the thrusts and even the Tungsten King fault, which is postthrust and has dropped the thrust pile to its present position. Contact metamorphism by the posttectonic intrusions has healed faults and hornfelsed susceptible beds. In spite of this metamorphism the formations retain enough distinctive features to be recognized with considerable assurance at most places, and thus provide a basis for mapping and structural interpretation.

In general the thrust pile consists of many thin and nearly horizontal thrust plates and wedges containing formations from the Pinal schist to the Horquilla limestone stacked over one another to a total thickness that may nowhere exceed 750 feet. This estimate of total thickness is based on the relation of thrust faults to topography; this relation everywhere indicates very gentle dips. At the north end of the pile, the basal structural units were thrust over the Pinal schist but at the south end were thrust over the Morita and Cintura formations. The contact between the two overridden formations is concealed by the thrust plate but presumably is in a zone of moderately steep thrusts which are an extension of those along the northeast side of the Morita and Cintura formations east of the Texas Canyon stock. The actual relations may be considerably more complex than shown on section *N–N′* (pl. 2).

The largest single structural unit in the thrust pile is a plate of Horquilla limestone that extends for 1¾ miles from the quartz monzonite contact in Sheep Basin westward and southward to the southernmost outcrop of the thrust pile southeast of the San Pedro Ranch (pl. 1). This plate, which is probably at most a few hundred feet thick, separates the pile into upper and lower structural units.

North of the Horquilla plate and structurally below it, there is a complex of small plates in which all formations older than the Horquilla limestone are exposed. The details of structure are too complex and too masked by metamorphism for satisfactory interpretation, but the general pattern of fault blocks and stratigraphic units suggests the small-scale slicing, imbrication, and local folding that might take place where the sedimentary formations were peeled off the basement by overthrust in a general eastward direction. The lowest plate exposed in the northwest corner of the pile contains Pinal schist and Pioneer shale which have nearly the same attitude they have in the klippe half a mile to the north, suggesting the two may be parts of the same plate.

The structural units below the Horquilla plate are cut off on the west by the Tungsten King fault. Their eastern limit is uncertain because of Tertiary intrusions and alluvial cover. Half a mile east of the San Pedro Ranch, however, the Escabrosa and Abrigo formations crop out between the Horquilla plate and the Morita and Cintura formations. The fault at the base of the Horquilla plate and the top of the Escabrosa mass is well exposed at one place and is a nearly horizontal thrust zone containing lenses of sheared sandstone and conglomerate from the Morita and Cintura formations.

West of this locality the Escabrosa limestone crops out at intervals for half a mile between the Horquilla limestone on the east and the Tungsten King fault on the west. The structural relations between this limestone and the Horquilla are not known because aplite was intruded along the contact. Our interpretation that it represents a lower plate (pl. 2, section *O–O′*) is necessarily tentative but is consistent with other evidence that these plates are nearly horizontal.

Thrust plates on top of the Horquilla plate are preserved in the form of an erosional remnant in a low hill three-quarters of a mile northeast of the San Pedro Ranch. All formations between the Abrigo and the Black Prince are represented. As these formations are older than the Horquilla, their present position above it indicates considerable displacement. The thrust that outlines the remnant as a whole runs around three sides of the hill almost on the contour, suggesting it is everywhere within a few degrees of horizontal. The thrusts within the remnant evidently dip at slightly greater angles to the west and south and have an imbricate relation to the bounding thrust. (See pl. 2, section *N–N'*.) The entire remnant is probably only about 200 feet thick and is cut into seven imbricate slices individually 50 feet or less in thickness. Several of the imbricate slices are offset by small steep faults that appear to be postthrust but could be related in some way to the thrusting.

TUNGSTEN KING HORST

The Tungsten King horst is the upthrown block between the Tungsten King fault on the east and the South Camp fault on the northwest (pl. 5). It forms a strip about 5 miles long on the west side of the Little Dragoons from the lower end of Sheep Basin to the point of convergence of the bounding faults north of Hughes Canyon. The western and southern parts are concealed by alluvium in the San Pedro valley.

The exposed part of the horst consists entirely of Pinal schist and intrusive igneous rocks, making recognition of Late Cretaceous and early Tertiary structures difficult and necessarily inconclusive. In all parts of the horst, the Pinal schist shows the subhorizontal lineation characteristic of zones of intense Laramide deformation. Near the alluvium contact about a mile north of the San Pedro Ranch, this lineation has been so strongly developed that it obliterates the older lineation and schistosity, suggesting there may be a large Laramide thrust nearby. Near the head of Granite Canyon several very minor thrusts offset aplite dikes. A large normal fault parallel to the Tungsten King fault forms part of the contact between the Tungsten King granite and the Pinal schist. Lamprophyre dikes and quartz veins mainly parallel to the Tungsten King fault indicate widespread fissuring with this trend.

TUNGSTEN KING FAULT

The Tungsten King fault, which bounds the horst on the east, emerges from beneath the alluvium east of the San Pedro Ranch and trends north for more than 5 miles. The fault dips about 80° E. at the lower end of Sheep Basin but flattens to a dip of 30° to 50° E. in the central and probably the northern part. The flatter dipping parts have a winding course because of the topography. Throughout its length the fault is marked by a shear zone 1 to 30 or 40 feet wide intruded at many places by discontinuous dikes and lenses of lamprophyre, most of which are too small to be shown at the map scale. South of Hughes Canyon for a distance of 1½ miles the zone is mineralized here and there by quartz, scheelite, beryl, and base-metal sulfides. This part, known as the King vein, is discussed later (p. 159).

The Tungsten King fault could not be traced through the Pinal schist north of the Tungsten King granite and it may die out before it reaches the South Camp fault. In Hughes Canyon the fault is offset 600 feet, and a short distance south of the Tungsten King mine it is offset 300 feet by later eastward-trending faults discussed in the preceding section. Small transverse faults between these two have resulted in offsets of a few feet to few tens of feet, but no other fault offsets are known.

Displacement on the Tungsten King fault evidently was considerable for it truncates the thrust pile in Sheep Basin for 1½ miles and the Tungsten King granite mass for 2 miles, and neither of these structural elements appears on the opposite side of the fault. The Pinal schist is the only prefault formation that crops out on both sides to give direct indication of the character of the displacement. A nearly vertical band of metagraywacke north of Hughes Canyon and an ill-defined zone of small metabasalt masses in Sheep Basin, seem to have been offset only slightly by the fault, suggesting there was little lateral movement (pl. 5). The relations give no indication of what the vertical movement may have been.

The relation of thrust plates of Paleozoic and Cretaceous rocks in the hanging wall of the fault in the lower part of Sheep Basin, and the complete absence of these plates in the footwall of the fault seems to require a postthrust normal displacement of 1,000 feet or more. This movement took place before intrusion of Tertiary(?) aplite dikes, which cut the fault at several places. Thus, this movement is clearly part of the Late Cretaceous and early Tertiary deformation. It is possible of course that the movement was the last of a series of movements, the fault having originated earlier. Indeed local drag(?) effects in the schist suggest that it may have had reverse movement at one stage in its history.

SOUTH CAMP FAULT

The South Camp fault emerges from beneath the alluvium three-quarters of a mile north of Hughes Canyon. It here trends northeast and separates Tungsten King granite on the southeast from Pinal schist on the northwest (pl. 5). It turns north to form the west contact of the metagraywacke in the horst block and continues with northerly trend beyond the end of the horst for 1 to 1½ miles before it is finally concealed by alluvium. Exposed parts of the fault dip 60° to 65° W.

The South Camp fault is evidently a major normal fault, probably with greater displacement than the

Tungsten King fault. The downthrown hanging-wall block contains the Pioneer shale and a considerable part of the Paleozoic section, whereas the nearest exposures of these rocks in the footwall block are in the Lime Peak thrust plate more than a mile to the southeast and in the block below this thrust plate a comparable distance to the north. The hanging-wall block of the South Camp fault could represent either of these major structural units or part of both.

AREA WEST OF THE SOUTH CAMP FAULT

The downthrown block on the west or hanging-wall side of the South Camp fault is a complex of formations from the Pinal schist to the Horquilla limestone (pls. 1, 2). We tentatively assign the complex to the belt of thrusts (pl. 5, block 1).

POST-PALEOZOIC SYNCLINE

The exposures of post-Pinal rocks are so small and so broken by faults that several interpretations of their structure are possible, but the simplest and therefore the most probable interpretation is that the basic structural feature is a syncline which plunges northwest and is modified in detail by later faulting (pl. 2, section *L–L′*). The south limb of this fold strikes east and dips 30° to 40° N. and is represented by the Pinal, Bolsa, and Abrigo formations in normal depositional relation to one another. The north limb, represented by the Bolsa and Abrigo, crops out a mile farther north, strikes about N. 15° W. and dips 30° to 40° W. Both limbs are cut off by the South Camp fault on the east and concealed by alluvium on the west. Between the limbs as defined, the proper sequence of formations is locally modified by faulting; but the bedding has a synclinal structure conforming to that of the limbs, and the general sequence of formations is from older to younger down the axis and inward from the limbs.

THRUST FAULTS

The north limb of the syncline is broken by a low-dipping thrust fault on which younger rocks have overridden older. On the north side of South Camp Wash the thrust defines a small klippe offset by small faults that parallel the South Camp fault. The thrust plate here consists of the Martin and Escabrosa formations and lies on the Abrigo formation. On the south side of the wash the same thrust is exposed for 700 feet, and Escabrosa lies on Abrigo. The geologic relations at both localities suggest an eastward or northeastward overriding of 1,000 to 2,000 feet. The movement might have been greater, of course, but it is unlikely that this fault is a major thrust like the Lime Peak thrust or several others in the area. The Lime Peak thrust could lie either above or below.

There is some indication that a large thrust may cut the Pinal schist south of the syncline. The southern half of the Pinal schist outcrop is much sheared, and several narrow zones of silicification, brecciation, and mylonitization can be traced for distances of a few hundred to about a thousand feet. A lamprophyre dike has been intruded into one of these zones, which trend about N. 75° W. The zones appear to dip to the south, but the amount of dip could not be determined. A conspicuous Laramide(?) lineation plunging 6° to 50° S. has also been developed in this area, commonly to the extent of obliterating other structure in the schist.

STEEP FAULTS

The Paleozoic rocks are broken by steep faults trending north and also by a group of faults trending northeast. The principal fault of the first set, the South Camp fault, is clearly younger than the other structural features. Other faults of the set cut and offset the thrust plate north of South Camp Wash. A northeastward-trending fault probably cuts the same plate south of the wash near the south Camp fault, but the relations are not well exposed and cannot be interpreted unequivocally. There is no consistent age relation between the two groups of steep faults, and therefore we regard them as nearly contemporaneous and both postthrust. (See pl. 2, sections *K–K′* and *L–L′*.)

In general the northward-trending faults have their downthrown side to the west. This is obvious for the South Camp fault as a whole, and also for 5 of 6 lenticular fault blocks along its course, most of which are too small to show at the map scale. West of the South Camp fault, two northward-trending faults have offset the base of the Pioneer shale 200 feet and 400 feet respectively, in a left-lateral sense. Two additional faults with the same trend are responsible for fault blocks of Pioneer shale and Horquilla limestone on the west side of the schist outcrop several hundred yards to the southwest. If these latter faults are of the same kind as the others, as suggested by their trend and by the general parallelism of bedding in the fault blocks, the indicated offsets are 700 feet and perhaps 3,000 feet respectively, also in a left-lateral direction. All these relations indicate consistent downthrow to the west. Presumably all the faults are normal faults, like the South Camp fault which dips 60° to 65° W. where it is exposed. Although lateral movement is not required by the geological relations, it could have been a contributing factor in each case.

Only two of the northeastward-trending faults are large enough to justify special comment. These define a graben of the Escabrosa and Martin formations 300 feet wide and 2,000 feet long in the south limb of the syncline. The fault along the southeast side of the graben dips 80° to 85° SE. where it is exposed and thus is of the reverse type. The fault along the northwest side also dips southeast but at considerably lower angles, at one place at only 25°. The relation of formations suggests it is a normal fault. The graben block between the faults is apparently downthrown between 300 and 600 feet (pl. 2, section *L–L'*. Some of the apparent downthrow could be due to lateral movements.

NORTHEASTERN PART OF THE RANGE

The northeastern part of the Little Dragoon Mountains—bounded on the south and west by the Centurion fault, Texas Canyon quartz monzonite, Lime Peak thrust, Tungsten King fault, and South Camp fault—is structurally below the major thrusts of the range and is part of structural block 2 (pl. 5). This part of the block seems to represent a large left-lateral flexure in the generally northeastward-dipping Paleozoic rocks, which cross the block from the Gunnison Hills to Kelsey Canyon. The major flexure is modified by minor folds and a multitude of steep faults. The few small thrust faults known are characterized by overriding from the east, instead of from the southwest as in block 1.

FOLDS

The major flexure in the upper Precambrian and Paleozoic rocks is expressed by a change in strike without significant change in dip. The beds in the western part of the fold 2 miles southeast of Deepwell Ranch strike N. 70° E. and dip 35° N. on the average. In the vicinity of Johnson they have swung around to an attitude of about N. 50° W., 35° NE. Alluvium conceals the structure east of the Keystone mine, but relations at the Legal Tender and Standard prospects, 1½ to 2 miles to the southeast, suggest the flexure continues south in the basin between the Little Dragoons and the Gunnison Hills (pl. 2, section *O–O'*). At the Legal Tender prospect, beds of the Horquilla limestone strike N. 24° W. and dip 47° NE. on the average (fig. 37). At the Standard prospect no Paleozoic rocks are exposed, but subsurface data indicate that beds of the Bolsa and Abrigo formations there have nearly the same attitude (p. 181).

South of the Centurion fault, formations of Paleozoic age dip about 55° SW., in contrast to the northeast dip at the Legal Tender and Standard prospects. There is no indication of an intervening anticlinal axis to explain the reversal in direction of dip (pl. 5). If the main movement on the Centurion fault was of the thrust type, as suggested on pages 105–106, an anticlinal axis in this location is not necessary, and the northeastward-dipping beds at the Legal Tender and Standard prospects could extend, with the same attitude, as far as the Centurion fault.

Minor flexures are superposed on the major flexure of the Paleozoic rocks. Near Johnson, Baker (1953, p. 1273–1274) recognized two sets of shallow warps, called Manto folds and Winze folds, which he believed were of great importance in localizing ore bodies. The axes of the two sets of folds are at right angles to each other: the Manto folds trend S. 70° to 90° E. and plunge 15° E.; the Winze folds trend N. 10° W. and plunge 30° N. The folds in both sets are very shallow and generally obscure. They were first recognized in the Republic mine, and this mine contains the best of the few examples now known.

In the northeastern part of the Little Dragoons as a whole, the principal minor folds plunge north and thus have the characteristics of Winze folds. Northeast of the Keystone mine a very gentle anticline and syncline with this trend are indicated by bedding attitudes and the pattern of formations (pl. 6). A larger roll of the same kind is found west of Johnson, the anticlinal axis being 1 mile and the synclinal axis about 2 miles west of the town. These flexures die out within 2 miles to the north. Other minor flexures apparently trending north are found northwest of the Seven Dash Ranch, but the relations are obscured by faulting. All these minor folds have the same trend as the syncline or synclines in the Lime Peak-Sheep Basin area and may be a weaker expression of the same stresses.

South of Johnson, local folds of a very different type appear in the upper Precambrian rocks within about a thousand feet of the Texas Canyon stock. These folds are described in detail on page 79 and are attributed to lateral shouldering action of the stock. If this interpretation is correct, they are younger than the other folds and thrust faults.

THRUST FAULTS AND RELATED STRUCTURAL FEATURES

Near the southwest edge of the area here under consideration, certain structural features are associated in space with the Lime Peak thrust. These features, discussed in an earlier section, include klippen of the Lime Peak plate southwest of Johnson Peak and several structural features wholly within the Pinal schist, such as drag folds northwest of Lime Peak and a large northward buckle southeast of the peak. Other thrust faults and related phenomena are scarce and minor.

Of the many faults that cut the Paleozoic rocks on the northeast side of the range, only one, 1¾ miles northwest of the Seven Dash Ranch, seems certainly to be of the thrust type. At this locality the base of the Pioneer shale is offset 750 feet in a right-lateral sense by an apparently subhorizontal fault trending

N. 25° E. across the common boundary of secs. 7 and 18, T. 15 S., R. 22 E. (pl. 1). The fault is offset by two small steep faults with northwest trend and downthrow on the northeast. As the subhorizontal fault actually dips gently to the southeast, it is offset in a direction opposite the offset of the beds, which dip north. The flat fault is offset in a left-lateral direction: 450 feet by the first small fault and at least 400 feet by the second which displaces it north beneath the alluvium. These offsets are large compared to the offsets of the beds, because the fault has a gentler dip. As the beds dip only 30° or 35°, the fault must dip considerably less than 15°. We regard it therefore as a thrust fault. The thrust direction must have been to the west or southwest to give the offset observed. This direction is nearly opposite the apparent direction of major thrusting in the southern belt of deformation but is compatible with the indicated direction of thrusting north of the Johnny Lyon Hills, discussed on page 122.

About half a mile east of the Seven Dash Ranch, there is a possible thrust trending north subparallel to the strike of the beds. It repeats part of the section, and at one place brings the Dripping Spring quartzite against the Abrigo formation. The winding trace of the fault on the topography suggests that it dips to the east and therefore is a reverse fault. If this is correct the apparent direction of overriding was to the west as it was in the case of the small thrust just described.

NORMAL AND STEEP REVERSE FAULTS

Normal and steep reverse faults in this part of the Little Dragoons have three principal trends: northeast, roughly east, and north-northwest. In the Johnson mining area, these faults are called Northeasters, Easters, and Northwesters respectively. All appear to have been active at virtually the same time, because faults with each trend locally cut faults with each of the other trends. Activity continued into postthrust time, for the small thrust northwest of the Seven Dash Ranch and klippen of the Lime Peak thrust plate have been displaced. Many of the faults have had several periods of movement and some may have formed initially in pre-Cretaceous time.

The dip of the faults is generally more than 55° where it can be measured directly or be inferred from the trace of the fault on the topography. The hanging-wall block is generally downthrown to give vertical separations ranging from a few inches to about a thousand feet. Most of the observed displacements could have resulted equally well from dip-slip, strike-slip, or oblique-slip movement on the fault planes; but the lateral component of movement was minor on those few faults for which it can be appraised. Where faults cut two planes of reference, like a bed or an older fault, the direction and amount of offset generally reflect the direction and amount of dip of the reference planes; reference planes with opposing dips are characteristically offset in opposite directions. These relations, which indicate mainly dip-slip movement on the fault plane, are evident in the case of the small northwestward-trending faults that offset the thrust northwest of the Seven Dash Ranch. A quarter of a mile north of Johnson Peak a conspicuous eastward-trending fault shows analogous relations. The faulting resulted in substanital left-lateral offset of the beds which dip 20° E. and much smaller right-lateral offset of a fault which dips steeply to the west. A few other illustrations will be found on examination of the geologic map.

A notable exception to the generally steep dips of the faults is found among the Easters in the Johnson district. Most of these faults dip 30° to 50° S. which is opposite to the dip direction of the beds. In most cases the hanging-wall block is downthrown, indicating that they are normal faults. As normal faults with such low dips are rare, some explanation is required. One possibility is that they formed in pre-Cretaceous time before the beds were tilted into their present attitude. If the beds are restored to a horizontal position by rotation about an axis parallel to their present strike, the faults would be steepened to 60° to 90° S., a common attitude for normal faults. Pre-Cretaceous faults that trend east are found in the Gunnison Hills. Faulting was certainly not confined to pre-Cretaceous time, however, for these faults are among the most recently active faults in the Johnson district, and very commonly had some post-ore movement. The late stresses may have taken advantage of considerably older breaks.

In the Republic mine, two Easters, the 1400 and 1600 faults, are reverse faults and exceptions to the general pattern. If these unusual faults resulted from lateral compression one would expect them to be among the lowest-dipping faults of the group, but they are distinctly steeper than the majority that had normal movement. The reconstruction suggested in the preceding paragraph would rotate them through the vertical to dip steeply to the north. (See pl. 10.) Thus if they formed prior to the tilting, they were initially normal faults.

In each of several areas the pattern of offset of beds is remarkably consistent. In the Johnson district, for example, the offsets are predominantly right lateral, whether by northeastward-, eastward-, or northwestward-trending faults. About a mile to the west on the opposite limb of a gentle anticline the offsets are as consistently left lateral (pl. 6). The effect of the faulting was to depress the limbs of the flexure and to emphasize the curve in the map pattern of the formations. Between the flexure and the vicinity of the

Seven Dash Ranch the pattern of offsets is not very consistent, but northwest of the ranch the offsets are again consistently right lateral. The relations suggest response to local rather than pervasive regional stress conditions.

GUNNISON HILLS

The Gunnison Hills, which are part of structural block 2 (pl. 5), are a faulted homocline of formations of Paleozoic and Mesozoic ages which dip 25° to 45° NE. The strike of the beds of Paleozoic age swings from N. 15° W. at the quadrangle boundary 3 miles northeast of Dragoon to N. 45° W. near Highway 86. Thus the beds are parallel to the segment of Paleozoic rocks that is beneath the alluvium southeast of Johnson. The Gunnison Hills are probably part of this segment uplifted by a major fault along the west side of the hills. (See pl. 2, section *O′–O′*.) This fault, which we have called the Gunnison Hills fault, is exposed north of Highway 86 where it strikes about N. 10° W., dips 74° W., and has brought Glance conglomerate on the east against older alluvium on the west. Obviously this part of the fault records late Cenozoic movements. The concealed extension to the south, which we believe defines the early straight western side of the hills, undoubtedly had important late Cenozoic movement also, bringing easily eroded alluvium next to the more resistant Paleozoic rocks. Possibly the fault also had earlier movement, as it parallels Late Cretaceous or early Tertiary faults in the Little Dragoons.

The Gunnison Hills block is broken by many transverse faults trending northeast and east, parallel to fault trends in the Little Dragoons and definitely older than the latest movements on the Gunnison Hills fault. Several of these faults are large. West of the lower end of Walnut Gap, for example, formations from the Martin to the Horquilla crop out in a horst less than a mile wide and standing 1,500 to 2,000 feet structurally higher than the downthrown blocks on the two sides. The fault on the north side of the horst trends N. 75° to 80° W. and appears to be steep. The fault on the south side trends about N. 65° E., and its trace on the topography suggests a moderate southeast dip. Other large faults, in part of pre-Cretaceous age, are found east of Walnut Gap. The offset of beds is nowhere consistently right lateral or left lateral as it is in parts of the Little Dragoons and in the area north of the Johnny Lyon Hills.

A concealed fault trending northwest through Walnut Gap is suggested by indirect structural and physiographic evidence. The rocks east of the gap are broken by numerous transverse faults, none of which has been recognized on the west side of the gap. In sec. 28, T. 15 S., R. 23 E., a zone of normal faults (in part pre-Cretaceous) strike northeast and have offset the base of the Concha limestone a total of about 2,000 feet in a right-lateral sense (pl. 1). This offset is equivalent to a vertical separation of about 1,500 feet. Faults of this magnitude could not die out in about a thousand feet, the width of the gap in this area. Presumably the faults end against or are much offset by a fault in the gap. This interpretation could also explain the straight course of the gap across formations ranging from the Horquilla to Concha limestones. An alternative interpretation is that the large northeastward-striking faults east of Walnut Gap turn to a south or southeast strike in the gap and therefore do not cross it.

North of Highway 86 the few bedding attitudes that could be determined in the massive Glance conglomerate suggest that the formation has been folded into a broad anticlinal flexure which plunges northeast roughly perpendicular to the axis of the homocline farther south. In the vicinity of Highway 86 the beds swing to a northeast strike and flatten to dip 10° to 30° SE. Half a mile to the north the beds strike west to southwest and dip 20° to 25° N. The beds in the northern part have nearly the same attitude as the Glance beds that crop out at the south end of the Steele Hills.

STEELE HILLS AREA

The Steele Hills consist of gently dipping units of the Galiuro volcanics and Threelinks conglomerate lying on closely folded beds of the Bisbee group (pl. 5; pl. 2, section *J–J′*). The pre-Tertiary rocks, whose structure is our present concern, crop out only on the south and northeast sides of the hills. On the northeast side of the hills the Morita and Cintura formations are extensively exposed and are in folds with an average trend of N. 40° W., nearly parallel to the homoclines of Paleozoic rocks in the Gunnison Hills and south of Kelsey Canyon. The folds are overturned to the northeast at a few places. Near the south end of the hills, north of Antelope Tank, the Morita and Cintura formations are also exposed. The beds are in isoclinal folds that trend N. 65° W. and are upright or slightly overturned to the northeast.

A short distance west, south, and southeast of Antelope Tank, there are isolated outcrops of the Glance conglomerate with distinctly different structure. In the southern and greater part of the outcrop area the beds strike northeast and dip about 20° NW. Toward the north the strike swings to the east and even a little to the south of east, and the dip steepens locally to as much as 60° or 70°. These Glance outcrops are probably part of the Gunnison Hills block, which is partly concealed by alluvium (pl. 5).

Near Antelope Tank a concealed fault, called the Antelope Tank fault, trends northwest between the outcrops of Glance conglomerate on the south and the outcrops of the Galiuro, Threelinks, and Morita and Cintura formations on the north. The evidence for this fault is as follows: (1) The Glance conglomerate immediately south of Antelope Tank and the Galiuro and Threelinks formations immediately north of the tank dip toward one another (pl. 1), indicating a fault relation. (2) In the same area the structures in the Glance conglomerate and in the Morita and Cintura formations are so different in character and general trend (pl. 5) that a thrust or strike-slip fault between them is suggested; the Glance conglomerate south of Antelope Tank is in gentle flexures that plunge northeast whereas the Morita and Cintura formations north of the tank are in isoclinal folds that trend northwest. The local change in dip and strike in the northern part of the Glance outcrops (pl. 1) resembles the drag effect on a fault. (3) The aeromagnetic map of the Dragoon and Cochise quadrangles (U.S. Geol. Survey, 1952) shows a conspicuous magnetic anomaly which follows a remarkably straight line (S. 65° to 70° E.) from Kelsey Canyon through Antelope Tank to the east edge of the Cochise quadrangle, a total distance of more than 30 miles. Our interpretation of the aeromagnetic data (p. 125) is the basis for extending the Antelope Tank fault as shown on the structure map (pl. 5). (4) Within the limits of structural block 2 (pl. 5), the bedrock formations which are exposed south of the fault are not exposed north of it, and vice versa; even the older alluvium exposed on the two sides is, for the most part, very different lithologically.

The data suggest that the Antelope Tank fault may be a wrench fault (Moody and Hill, 1956, p. 1208, 1214, 1215). Its probable long straight course suggests that the fault is nearly vertical and also nearly planar (not curved). The distribution of formations indicates the north side was downthrown in post-Galiuro time. Apparent drag effects in the Tertiary rocks near Antelope Tank suggest that the actual fault movement may have been horizontal and not vertical; the Galiuro and Threelinks formations appear to have been dragged downward next to the fault (pl. 1), instead of upward as would be expected if the movement had been vertical.

The fault was probably active in pre-Galiuro as well as post-Galiuro time. The local isoclinal folds in the Morita and Cintura formations north of Antelope Tank are nearly parallel to the fault and distinctly oblique to other folds in the vicinity (pl. 5). The isoclinal folds are certainly pre-Galiuro in origin, and if they are due to drag on the fault as seems probable, the fault must have been active in Late Cretaceous or early Tertiary time. The direction and amount of displacement during Late Cretaceous or early Tertiary time are obscure; the structural relief that resulted was evidently much less than that on the parallel fault which forms the boundary of structural block 3 at the south end of the Winchester Mountains (pl. 5).

WINCHESTER MOUNTAINS

The small exposures of pre-Tertiary rocks in the Winchester Mountains are cut by a major Late Cretaceous or early Tertiary fault zone, which forms the northeast boundary of structural block 2 (pl. 5). The fault zone, which is exposed for less than half a mile in the NE¼ sec. 5, T. 14 S., R. 23 E., trends N. 65° to 70° W., parallel to the Antelope Tank fault. On the north side of the fault zone is granite of Precambrian age. On the south side are intensely deformed sedimentary and volcanic rocks which we have assigned tentatively to the Cretaceous system but which could be of early Tertiary age. The indicated structural relief in the pre-Galiuro formations is probably many thousands of feet and is larger than at any other locality in the Dragoon quadrangle; but the Galiuro volcanics are not affected.

The fault zone actually consists of two nearly parallel faults which are several hundred feet apart and define a fault slice of the Escabrosa, Black Prince, and Horquilla limestones. These limestones strike N. 40° to 45° W. and are overturned to the northeast, so that they dip about 60° SW. The fault which bounds them on the north has a curving trace on the topography, suggesting that it dips gently to the southwest. The direction of overturning in the limestone suggests it is a thrust fault on which the hanging-wall block has overridden from the southwest. This interpretation, shown on the structure map (pl. 5) and on section *I–I′* (pl. 2), is necessarily tentative because of the short length of exposure of the fault in an area of only moderate relief. Moreover, shear planes within the fault zone dip 70° N. at the single locality where they could be observed. It is possible, of course, that the shear planes express late Tertiary or Quaternary fault movements, which were abundant in this area and were of a different type from the earlier faulting.

The fault that bounds the sliver of limestone of Paleozoic age on the south is regarded as a steeper branch of the northern thrust (pl 2, section *I–I′*). It contains a narrow fault slice of Horquilla limestone shown on the geologic map and another of Glance conglomerate too small to show at the map scale.

Some information on the structure of the block of Precambrian rocks north of the fault zone can be obtained from outcrops in Severin Canyon north of the Dragoon quadrangle. Less than a quarter of a mile north of the quadrangle boundary, the Precambrian granite contains an infaulted lens of upper Paleozoic limestone, 600 or 700 feet wide and several thousand feet long, with its long axis trending N. 70° W. parallel to the lens at the south edge of the granite. The faults that bound both lenses are probably parts of the same major fault zone. About half a mile farther north the Bolsa quartzite rests with depositional contact on the granite. The quartzite beds, though offset by small faults and interrupted by an infaulted block of limestone, are exposed for about 2 miles in the west wall of the canyon and in this distance have very gentle dips, ranging from horizontal to perhaps 20° to 25° SW. Post-Cambrian folding of this block was evidently slight.

The two fault slivers of limestone of Paleozoic age have been silicified here and there to form lenses of jasperoid as much as 100 feet wide and 1,000 feet long. They are reported to contain concentrations of silver and have been prospected as part of what is known as the Winchester mining district. The largest body of jasperoid within the Dragoon quadrangle is about 100 feet wide and 700 feet long and lies next to the fault that bounds the Paleozoic rocks on the north. Smaller jasperoid masses commonly have a more northerly trend to give an echelon pattern.

The Cretaceous(?) sedimentary and volcanic rocks, south of the major fault zone, strike northwest virtually parallel to the bounding fault; and the top of the beds seems to be consistently to the southwest. The beds dip about 50° SW. near the fault but steepen to vertical ¼ to ½ mile southwest of the fault. Farther southwest the dip gradually flattens again to 20° to 30° SW. The most plausible explanation we can suggest for this puzzling structure is that it represents part of a major fold in which a part of the vertical northeast limb was later dragged back toward its original horizontal position by friction on the bounding thrust.

The large fault zone at the south end of the Winchester Mountains and the Antelope Tank fault are parallel to and almost in line with conspicuous faults and folds shown on the geologic map of Arizona (Darton and others, 1924) in the Dos Cabezas Mountains to the east and in the northern part of the Santa Catalina Mountains to the west. The relations tend to support the suggestion first made by Hill (1902, p. 173) that there is a line of faulting in this position extending from southern Texas to the vicinity of Los Angeles, Calif., oblique to the general Cordilleran trend. This line was called the Texas lineament by Ransome (1915b, p. 295), and the segment in the Trans-Pecos region of Texas has been discussed in considerable detail by C. L. Baker (1934, p. 206–214). Though broad and not very sharply defined, the zone seems to mark an old and important tectonic line. Among the major tectonic features along its course are:

1. The transverse ranges of southern California.
2. The transverse ranges in west-central Arizona, best expressed by the great sigmoid curve of the Wickenburg, Vulture, Harcuva, and Harquahala Mountains.
3. The northern flank of the Sonoran geosyncline. This is best indicated in Arizona by the abrupt pinchout to the north of the thick section of Lower Cretaceous rocks (McKee, 1951, pl. 3A).
4. Between southeastern Arizona and west Texas, the zone separates two structural provinces. The area in and south of the zone is characterized by large thrusts and overfolds. The area to the north suggests the faulted margin of the Colorado Plateau; steep faults are abundant, and overthrusts are subordinate.

Baker (1934, p. 214) and Moody and Hill (1956, p. 1229) have suggested the Texas lineament represents a zone of steep strike-slip or wrench faults comparable to the San Andreas fault of California. The long straight courses of faults that coincide with the lineament in southeastern Arizona tend to support this interpretation. Aeromagnetic data suggest that the Antelope Tank fault has a straight course (N. 65° to 70° W.) for at least 30 miles. The position and trend of the large fault zone at the south end of the Winchester Mountains suggest that it may be the same fault mapped in the Dos Cabezas and northern Santa Cataline Mountains (Darton and others, 1924). If so the fault has a slightly undulating course (averaging N. 70° W.) for nearly 100 miles. The apparent thrust movement at the south end of the Winchester Mountains may express late and relatively superficial faulting in a zone with a complex history.

JOHNNY LYON HILLS

The Johnny Lyon Hills constitute the part of the southern belt of thrusts (pl. 5, block 1) northwest of Tres Alamos Wash between the Dragoon quadrangle boundary and a point about 2 miles south of Deepwell Ranch. The thrust plates are composed of formations from the Pinal schist to the Earp formation. The principal thrust direction appears to have been from southwest to northeast. Several of the principal plates evidently moved in this direction. Others can be interpreted equally well by movement in any one of several directions, and some are most readily interpreted by movement toward the northwest.

At places in the eastern part of the Johnny Lyon Hills area, Paleozoic rocks form an overlapping series of continuous and discontinuous plates stacked as many as 3 or 4 deep on the basement rocks. To the west, thrust plates composed wholly of lower Precambrian rocks are exposed. In the eastern part of the area, there is a persistent relation of a lower plate containing Apache group and formations of Cambrian age, an intermediate plate or plates containing Carboniferous strata, and an overlying plate of breccia derived from the Escabrosa and Black Prince limestones (fig. 25).

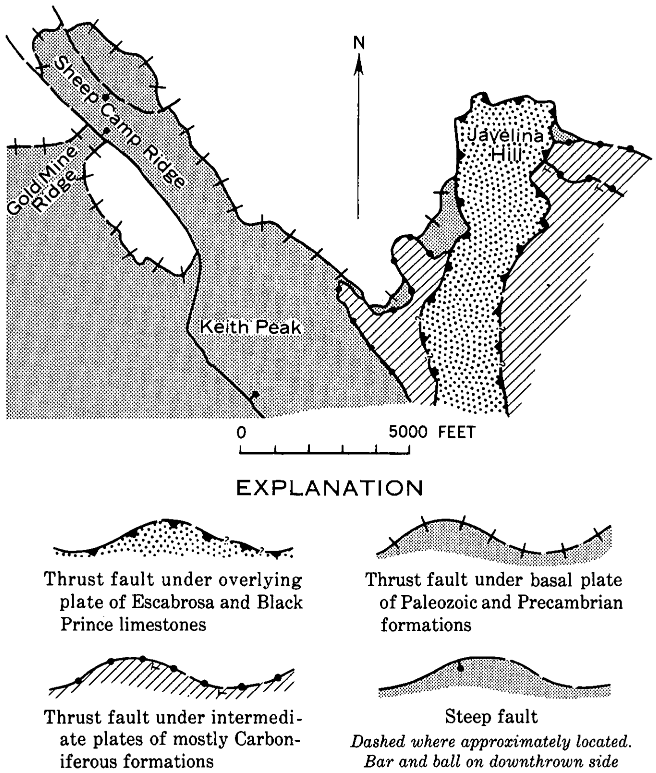

FIGURE 25.—Sketch map of the eastern Johnny Lyon Hills showing classification of thrust plates according to formation composition.

Though the various plates are not necessarily continuous at present and may never have been so, the sequence in space provides a convenient basis for organizing the detailed discussion that follows. The plates containing upper Precambrian and Paleozoic rocks will be discussed first, beginning with the lowest and presumably oldest plates. The thrust faults entirely in lower Precambrian rocks will be described last, as their relation to the others is necessarily a matter of interpretation. Local names for certain physical features, indicated on the sketch map, will be used in the discussion.

THRUST PLATES CONTAINING UPPER PRECAMBRIAN AND CAMBRIAN STRATA

EXPOSURES ON THE FLANKS OF JAVELINA HILL

On the west side of Javelina Hill, Apache group and Cambrian rocks crop out in a wedge between the Pinal schist on the west, the Escabrosa breccia plate on the east, and a plate of Horquilla limestone on the south. The beds in the wedge dip southeast and east and the formational sequence is normal for a depositional relation to the schist. However, a major shear zone at the base of the wedge, the absence of the Scanlan conglomerate, great reduction in the thickness of each of the stratigraphic units, and pervasive fracturing and brecciation belie the apparently normal stratigraphic relations and indicate that the wedge represents part of a thrust plate. The beds in this plate and apparently the underlying thrust are offset in a left-lateral direction by small steep faults trending north-northwest, only three of which can be shown at the map scale. There is no evidence that these faults, or a complementary(?) east-northeast right-lateral fault at the north end of the wedge, cut the overlying breccia plate. As the faults seem to cut the sole thrust, they probably formed during overriding of a higher thrust plate. If interpreted as wrench faults associated with the earlier thrusting, movement toward the northwest is suggested.

On the northeast side of Javelina Hill the Martin and Abrigo formations crop out in a small triangular block between the Pinal schist, an intermediate plate of Carboniferous rocks, and the Escabrosa breccia plate. The triangular block is structurally below the other plates, probably in slice relation to them and possibly once part of the plate discussed in the preceding paragraph (pl. 2, section *E–E′*).

KEITH PEAK AND SHEEP CAMP RIDGE

The lowest fault on the east side of Keith Peak is a thrust which underlies all of Keith Peak and Sheep Camp Ridge (pl. 2, sections *D–D′*, *E–E′*, *F–F′*). It can be followed almost continuously from the alluvium in the NE¼ sec. 21, T. 15 S., R. 21 E., northwestward 2½ miles around the north end of Sheep Camp Ridge. Above the thrust are rocks ranging from Pinal schist and granodiorite to the Horquilla limestone. The plate rests on the Pinal schist under Keith Peak and on granodiorite under Sheep Camp Ridge. The sole thrust dips 5° to 20° SW. along most of its trace, but at the northwestern extremity of Sheep Camp Ridge its attitude reverses and dips 26° E. The trace is marked by a continuous zone of slices and blocks from every formation in the plate; sheared Bolsa quartzite commonly forms resistant slices as much as 1,000 feet in outcrop length.

A postthrust normal fault, which trends N. 30° W. and can be followed for about 3 miles, offsets the thrust plate and forms the west boundary of the part making up Sheep Camp Ridge (pl. 2, section *D–D′*). This fault dips 50° to 60° E. and has an apparent stratigraphic throw of more than 800 feet on the northwest side of Keith Peak. However, local thinning of the formations prior to this faulting has exaggerated the minimum throw, which is actually about 500 feet including drag offsets. In the upthrown block west of the fault, a thrust which is evidently the offset segment of the Sheep Camp Ridge thrust is exposed at intervals for several miles northwest of Keith Ranch, and has lower Precambrian rocks in both walls. This segment will be discussed further in the section on thrust faults with lower Precambrian rocks in both walls.

The thrust plate in Sheep Camp Ridge has a homoclinal structure which dips about 40° NE. at the south end and 75° NE. at the north end. Drag on the normal fault along the west side of the ridge is probably responsible for the steepening to the north and also for the reversal in attitude of the sole thrust in this area. About 1,500 feet northeast of the large normal fault, a small subparallel fault almost parallel to the beds in the Abrigo formation had reverse movement and offset the sole thrust about 200 feet. There are also a few small cross faults confined to the thrust plate.

The thrust passing west under Sheep Camp Ridge cuts down the section so that both Pinal schist and granodiorite appear in the west flank of the plate but east of the normal fault. It is to be expected, therefore, that the exposures of the same thrust west of the normal fault will be between schist and granodiorite or wholly within one or the other of these formations. This is indeed the case.

The part of the thrust plate that makes Keith Peak has a synclinal structure plunging east-southeast. Topographically the crown of the peak consists of three ridges trending northeast, east, and south-southeast from the very top. All three ridges are maintained by the massive lower beds of the Escabrosa limestone. In the northeast ridge the beds strike northeast to east and dip about 30° S. As the beds pass under the top of the peak they swing to a northerly strike and dip 25° E. Passing into the south-southeast ridge they strike northwest and dip northeast at increasingly steep angles until they become steeply overturned just before disappearing under the alluvium of Tres Alamos Wash.

The core of the fold is complicated by an east-west hinge fault between the northeast and east ridges. This fault dips 70° to 75° S. and has a maximum stratigraphic throw of about 300 feet at its east end. Horquilla limestone on the hanging-wall side has been down dropped against the Escabrosa. As the fault is followed westward toward the crest of Keith Peak the displacement decreases rapidly and the fault appears to die out shortly before reaching the top.

On the northeast side of Keith Peak are a number of northward-trending faults which dip steeply to the east and have both normal and reverse apparent movements. These faults end to the north, against the thrust surface, and most of them end to the south against the hinge fault just described.

The postthrust normal fault on the west side of Sheep Camp Ridge cuts through the west side of the syncline. Northwest of the crest of Keith Peak this fault has several subsidiary branches which can be followed until they enter the underlying schist where they are not conspicuous. The main fault has a number of fault slivers in its zone and is very easy to trace on Keith Peak as long as it is oblique to the bedding. On the south side of the peak, however, it becomes first a strike fault and then close to a bedding-plane fault in the Abrigo formation. As a result its stratigraphic displacement almost disappears and it is difficult to follow until it passes obliquely into the Martin formation just before disappearing under the alluvium.

West of the normal fault are several steep faults trending east and northeast and a low-angle fault trending north. The low-angle fault dips east and has an indeterminate displacement. It is in part in the Pinal schist, where it is difficult to trace, but at a number of points it slices out the Scanlan conglomerate and the lower part of the Pioneer shale. Several of the high-angle faults end against it. A prospect tunnel has been driven through the low-angle fault in the SW¼ sec. 20, T. 15 S., R. 21 E. The tunnel, which has a bearing of N. 72° E., entered the Pinal schist about 150 feet west and 50 feet below the outcrop of the fault. At 230 feet it entered a 10-foot shear zone in the schist; above this zone Pioneer shale lies on a fault surface which strikes N. 1° W. and dips 29° E. The Scanlan conglomerate and the basal quartzite member of the Pioneer shale are missing. This eastward-dipping fault is not expressed by any important apparent displacement in the Precambrian rhyolite porphyry zone in the Pinal schist and is considered to be subordinate and perhaps conjugate to the principal westward-dipping thrust under Keith Peak.

INTERMEDIATE THRUST PLATES MOSTLY OF CARBONIFEROUS ROCKS

EXPOSURES EAST OF JAVELINA HILL

On the east side of Javelina Hill, two plates mostly of Carboniferous rocks intervene between the lowest wedge of Abrigo and Martin rocks and the overlying Escabrosa and Black Prince breccia plate. The northern and lower of the two intermediate plates consists of eastward-dipping beds of the Escabrosa, Black Prince, and Horquilla formations and is exposed in an east-west belt about a thousand feet wide and half a mile long between the breccia plate and the alluvium of Tres Alamos valley. Toward the east it overlaps the small Abrigo and Martin plate and rests directly on the schist. The fault that bounds the block on the north appears to dip south, but its attitude cannot be measured directly. The fault that bounds the block on the south dips 30° to 35° SSW. and has strong dip-slip slickensiding. Above this fault a continuous plate extends 1½ miles to the south.

The upper plate contains formations from the Martin to the Earp in an overturned syncline (pl. 2, section *G–G′*). The syncline plunges southeast and its limbs diverge more than 90° in strike (pl. 1). The upright limb strikes north and dips 48° E. on the average. The overturned limb strikes northwest and dips about 45° SW. In the core of the fold, shale and thin limestone of the Earp formation are tightly folded. The subordinate folds have inclined axial planes (striking N. 85° W., dipping 45° S.), axial-plane cleavage, and axes plunging 30° SE. The southwestward-dipping overturned limb includes a section of about 2,500 feet of beds from the Earp formation down to the upper part of the Martin formation. Though parts of the overturned limb are concealed by alluvium, the continuity of the fold, and hence the plate, can hardly be questioned.

The core of the fold is cut by a fold of small faults which trend west and dip 40° to 70° S. The faults are all right lateral and appear to be normal faults where the beds they intersect dip to the east; but where the faults intersect the southwestward-dipping overturned limb of the syncline they continue to be right lateral, indicating a large strike-slip component of movement. Drag folds in beds adjacent to the faults generally plunge steeply to the east; these folds also indicate lateral movement on the faults.

The relation of the faults to the major structure is puzzling. The overturned syncline with its subordinate folds and axial-plane cleavage must have been formed by southwest-northeast compression; but the small east-west transecting faults, which appear to be right-lateral wrench faults, suggest a principal stress along southeast-northwest lines. The faults, of course, could be later, perhaps related in some way to the emplacement of the overlying plate.

EXPOSURES BETWEEN JAVELINA HILL AND KEITH PEAK

In the valley between Javelina Hill and Keith Peak, bedrock exposures are limited to windows in the alluvium. Apparently a thin thrust plate of the Escabrosa, Black Prince, and Horquilla formations lies on the Keith Peak plate and is below the limestone breccia plate of Javelina Hill (pl. 1; pl. 2, section *E–E′*). The beds in the intermediate plate strike northwest; they dip northeast but are overturned locally. The sole thrust where exposed on the east slope of Keith Peak is a very undulating surface generally dipping to the east or south at angles locally as high as 40°. At the southwest base of Javelina Hill it probably dips to the west. At the southern end of the exposures of the plate, dissection of the alluvium has revealed an overlying thrust mass of Escabrosa breccia, evidently part of the plate that forms the top of Javelina Hill.

Evidence bearing on the direction of movement of the plate is somewhat conflicting. Slickensides on the sole fault plunge 40° E. downdip, in an exposure on the west side of the mass. On the northeast side of the mass, beds of Horquilla limestone crop out about 75 feet from the basal fault, stand nearly vertical, strike N. 15° E. and are cut by a coarse fracture cleavage that strikes N. 70° W. and dips 60° S. The cleavage may be interpreted as a shear phenomenon indicating movement from the south-southwest. If this plate was torn from the underlying Keith Peak plate, then movement from the south-southwest would be compatible with the present distribution of formations in both plates.

THRUST PLATE SOUTH OF KEITH PEAK

About 1½ miles south of Keith Peak in the SW¼ sec. 28, T. 15 S., R. 21 E., a small exposure shows a low-angle fault on which Escabrosa limestone has been thrust upon the Bolsa quartzite. The strike of the fault appears to swing from east to north within the 500 feet of exposed length. The right-lateral displacement of younger beds over older beds would be satisfied by thrusting from a direction more easterly than the strike of the beds which is about S. 25° E. The slices in the fault zone are from intermediate formations, and are therefore compatible with this interpretation.

THRUST PLATE OF BRECCIA DERIVED FROM THE ESCABROSA AND BLACK PRINCE LIMESTONES

Javelina Hill is capped by a thrust plate of resistant breccia derived from the Escabrosa and Black Prince formations. The lithology of the breccia was described in a preceding section (p. 58). The breccia plate has overridden the lower plates of Paleozoic rocks and at the north rests on the Pinal schist of the autochthonous block below them (fig. 26). Its intensely brecciated character distinguishes it from all other thrust masses in the Dragoon quadrangle.

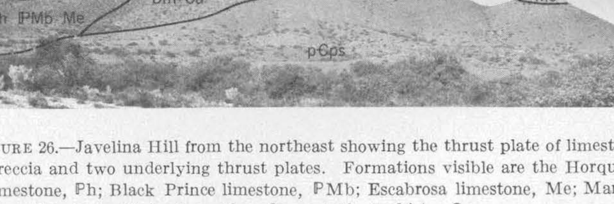

FIGURE 26.—Javelina Hill from the northeast showing the thrust plate of limestone breccia and two underlying thrust plates. Formations visible are the Horquilla limestone, Ph; Black Prince limestone, PMb; Escabrosa limestone, Me; Martin formation, Dm; Abrigo formation, Ca, and Pinal schist, pCps.

The fault beneath the plate can be traced continuously around the east, north, and west sides of a crudely rectangular block about a mile long north south and half a mile wide east west. On the west side its location can be fixed for another two-thirds of a mile to the south by erosional windows in the alluvium. On the northeast side it defines a small but conspicuous klippe resting on the Pinal schist (right side of fig. 26). The fault has a general dip to the south but is sufficiently undulating to dip in all quadrants locally. The sheared zone between the limestone breccia and the schist is remarkablv thin. It is everywhere less than a foot thick and is composed entirely of schist fragments. Deformation relating to thrusting is not evident in the schist a few feet away.

The breccia plate is cut by a well-developed set of joints that strike about north and are vertical to near vertical. These joints are confined to the plate and must have formed during its emplacement. Therefore the character and pattern of the joints may yield information on the direction of movement. The joints can be mapped readily in the lower most intensely brecciated part of the plate exposed along the margins of the present remnant (fig. 27). In the massive cliffs of the northern edge of the plate and the klippe, they are grossly expressed by a vertical columnar structure (fig. 28). On the upper surface of the plate, solution by meteoric water has etched them out and shown they are very pervasive.

The joints are incipient in the sense that most of them show no visible separation between opposite walls, but only a greater tendency for solution. They are best developed in the finest breccia; indeed they do not cut most of the large fragments in the breccia.

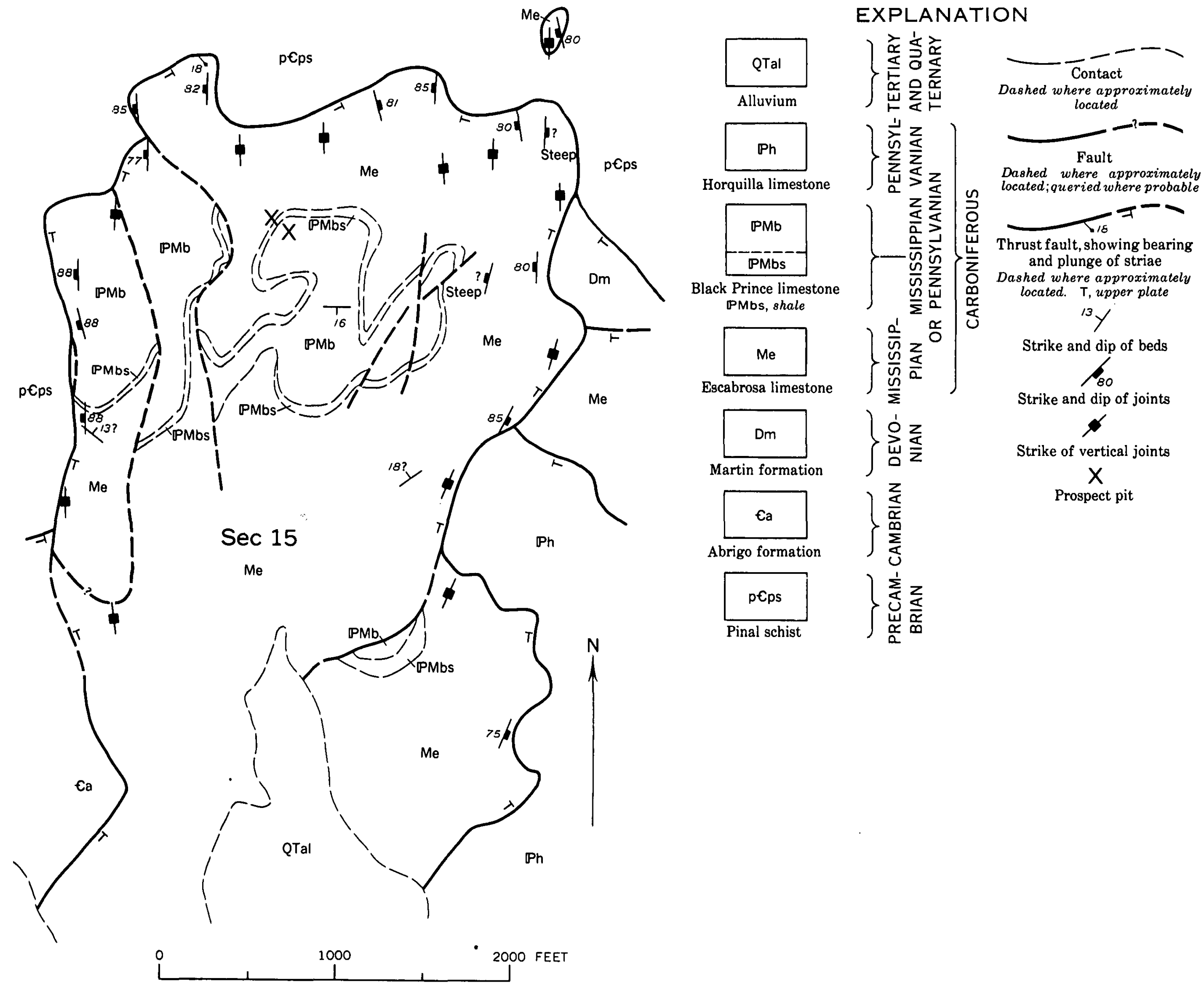

FIGURE 27.—Map of the limestone breccia plate on Javelina Hill (sec. 15, T. 15 S., R. 21 E.) showing joints and distribution of formations.

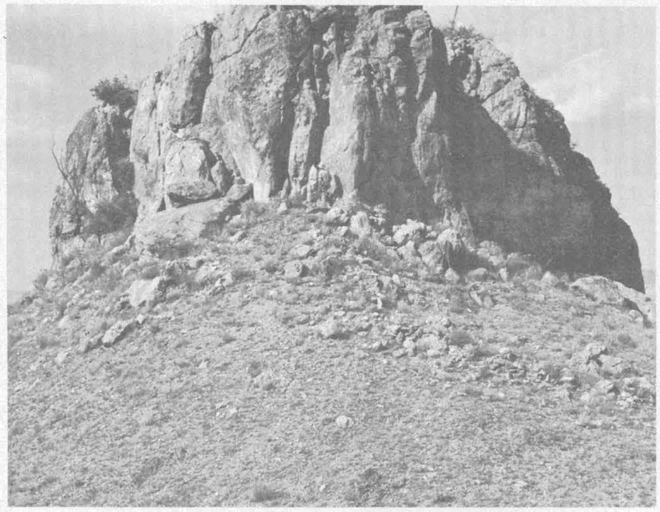

FIGURE 28.—Vertical jointing in the klippe of limestone breccia near the northeast corner of Javelina Hill. Pinal schist forms the smooth lower slope.

At places the joints show a flow divergence and convergence about the large pieces. Where a joint cuts through a fragment it does not offset the contacts or internal structures; nor do the joints offset the lenticular aggregates of chert breccia they traverse. The fine-grained part of the breccia now appears to have a bonding strength as great as the internal strength of the individual clasts. Hand specimens are broken out with difficulty, and the fracture surfaces truncate groundmass, chert, and limestone fragments alike. It is unlikely therefore that the joints have developed since cessation of plastic movement or they would be as common in the coarse fragments as in the comminuted material. If the joints were formed as shear phenomena at a time of plastic movement they must be incipient and must record the very closing episode; otherwise displacements along them would be common.

The joint pattern may yield information on the direction of final movement if correctly interpreted. Though the original thickness of the plate is not known, it is reasonable to speculate that the breccia was at the base of a thicker more or less continuous section, like that represented in the present remnant. Field and mocroscopic observations have confirmed that recrystallization is confined to the renewal of bonds in the tectonically milled breccia. The basal breccia may therefore be visualized as a plastic mass on which the higher rock moved. Within this mass differential resistance from the underlying surface might have set up incipient shear planes related to the direction of flow. The final aspect of this shear pattern could have been "frozen in" and subsequently etched out by weathering. If the joints are interpreted as incipient wrench faults, movement along an approximate line of N. 30° E. or N. 30° W. is suggested, but there is no indication of the sense of movement.

THRUST FAULTS WITH LOWER PRECAMBRIAN ROCKS IN BOTH WALLS

EXTENSION OF THE KEITH PEAK-SHEEP CAMP RIDGE THRUST

The thrust fault west of Sheep Camp Ridge (fig. 25) crops out in the ravine 300 yards east of Keith Ranch in the upthrown footwall block of the large normal fault that displaces it. The thrust, which is marked by a zone of shearing and cataclasis, forms the Pinal schist-granodiorite contact for about three-quarters of a mile. It first trends southwest and then curves to the northwest and enters the granodiorite where it can be traced continuously for another quarter of a mile. Beyond this point it appears to curve to the northeast again to another intersection with the normal fault. The granodiorite exposures near Keith Ranch are part of a fenster of the autochthonous block, completely surrounded by the thrust plate. Where exposed the thrust dips 25° to 30° SW., except near the normal fault where, due to drag, it dips south or southeast.

Several hundred yeards north of the fenster the thrust again appears west of the normal fault. The thrust here contains, for a length of half a mile, a few small lenticular slices of breccia derived from the formations of Paleozoic age exposed in Sheep Camp Ridge. Sheared granodiorite crops out at a number of points between the slices of breccia, and still farther west on the projection of the zone there is a conspicuous southward dipping shear zone 50 to 100 feet thick, which can be followed for more than 2,000 feet before talus conceals it.

Several lines of evidence suggest northeastward movement on this major thrust, including the downfaulted part under Keith Peak and Sheep Camp Ridge. The general trend of the sedimentary formations in the tilted rib of Sheep Camp Ridge and the fold on Keith Peak suggest northeast-southwest compression. The gradual overturning of the Escabrosa formation as it trends southeast from Keith Peak suggests active forces and block overriding from the southwest. The distribution of masses of Paleozoic breccias in the granodiorite west of Sheep Camp Ridge suggests fragments torn from the upper plate as it moved from southwest to northeast. Cleavage developed in slices of various formations in the fault zone dips southwest at angles usually greater than the dip of the fault. Rare drag folds in shale of the Abrigo at the north end of Sheep Camp Ridge also suggest movement from the southwest. The right-lateral offset of more than 2,000 feet of the granodiorite-Pinal schist contact might at first suggest movement from the east, but the great displacement indicated by other evidence, and the very slight offset of the rhyolite porphyry zone require the direction of movement to have been very close to the trend of the rhyolite zone (pl. 5). Assuming the average trend of the rhyolite zone to have been N. 45° E., the movement may have been approximately toward N. 40° E.

THRUST FAULTS SOUTHWEST OF KEITH PEAK

Many faults and shear zones, both high angle and low angle, cut the lower Precambrian rocks west of Keith Peak, but only two major thrust faults will be discussed in detail. These two faults are about 1½ miles southwest of the peak; they have sinuous northwest trends and dip away from each other (pl. 2, section *E–E'*). The distance between them ranges from 200 yards to about a mile (pl. 5).

The northeastern fault of the pair forms the granodiorite-schist contact for more than 4,000 feet and can be followed with some assurance for an additional several thousand feet in the schist on the east and the granodiorite on the west. Where the fault forms the schist-granodiorite contact, it is commonly silicified and well exposed. Its trace bends from west-northwest to north-northwest, in part because of topography and in part because of a change in attitude of the fault. The dip is about 30° NNE. east of the bend and as much as 45° NE. west of the bend. Slickensides nearly parallel to the dip of the fault are found on both parts.

This fault has offset the granodiorite-schist contact about 4,000 feet and the rhyolite porphyry zone about 2,500 feet, both in a left-lateral sense (pl. 5). As the slickensides indicate that at least part of the movement was nearly parallel to the strike of the displaced features (N. 35° E.), large movement on the fault is suggested to give the large offsets observed. As shown on section *E–E'* (pl. 2), we regard the fault as a thrust which either may be part of the major thrust that passes under Keith Peak or may intersect it in an indeterminate relation. No direct evidence was found to indicate whether the upper block moved northeast (downdip of fault) or southwest (updip of fault).

The southwestern low-angle fault of the pair can be traced for a distance of more than 2 miles and disappears beneath alluvium at both ends. It trends northwest to west and dips 25° to 40° SW. (average about 35° SW.). Dip-slip slickensiding was noted at several points.

The fault is represented by a wide zone of movement. In the western part, near the quadrangle boundary, it is marked by intensely crushed granodiorite. This crushed zone is about 300 feet wide and is as compact and tough as the undeformed rock. The eastern 1½ miles of the fault is marked by numerous fault slices, some of which are large enough to show on the geologic map (pl. 1). Fault slices of granodiorite are found in schist as much as 1,500 feet from the nearest exposure of granodiorite in the walls of the fault; and fault slices of schist are found in granodiorite as much as 1,500 feet from the nearest exposure of schist in the walls. Any interpretation of the direction and amount of movement on the fault must explain the presence of these slices.

The fault has offset the rhyolite porphyry zone about 500 feet and the schist granodiorite contact about 1,200 feet, both in a right-lateral sense (pl. 5). These apparent displacements are insufficient to account for the fault slices of schist in granodiorite or the slices of granodiorite in schist. The fault movement must have been nearly parallel to the strike of the rhyolite zone (N. 65° E.) to produce the relatively small apparent displacement of this zone and of the granodiorite-schist contact.

The fault has modified the older textures and structures of the rocks traversed. Within the principal zones of movement, both cataclastic and recrystallization features are evident in varying degrees. Adjacent to these zones there is generally a right-lateral drag in the strike of bedding and foliation in the Pinal schist and of the rhyolite porphyry sheets into a position nearly parallel to the fault. Within 25 feet of the fault and within the schist slices a new fracture cleavage nearly parallels the fault plane. A number of small folds in the footwall plunge S. 40° to 60° W. at 20° or 30°. This attitude places them in the class of *a*-lineations in the Sander coordinate system.

With an indicated direction of movement near N. 65° E., the problem of the sense of movement remains; that is, whether the movement was from the southwest or the northeast. Associated drag, slickensides, and folds suggest that thrusting was from the southwest. The right-lateral drag both above and below the fault indicates that if the movement came from the southwest it was from a bearing more to the south (S. 55° W.?) than S. 65° W., whereas if it was from the northeast it came from a bearing more to the east (N. 75° E.?) than N. 65° E. The slickensides observed do not directly provide a sense of movement but their average bearing, about S. 50° to 60° W., is more compatible with movement from the southwest. The same is true of the small folds below the thrust which trend about S. 50° W. on the average and are probably *a*-lineation features. The composition and distribution of fault slices in the zone are not accounted for readily by either hypothesis. The large schist slice in the granodiorite is more readily explained, however, by assuming movement from the southwest (pl. 1).

The dip of faults and fracture cleavage also suggest that the upper plate moved to the northeast. Where the fault zone consists of several faults and where the topography or the exposures indicate the attitudes of the several fault surfaces, the faults on the southwest are steeper than the others—a normal imbricate relation provided thrusting was from the southwest. The new cleavage developed adjacent to the faults is as steep or steeper than the nearby fault attitude. Such a cleavage is compatible with a shear pattern in which the upper plate moves updip.

The relation of the opposite-dipping faults to each other is an interesting problem. One possibility, of course, is that they are parts of an originally continuous fault separated now only by a fortuitous pattern of erosion. This would require a large and abrupt bend in the fault surface and also require that the two handing-wall blocks are parts of a once-continuous plate. The discrepancy in the orientation and position of the rhyolite zones on the two hanging-wall blocks would not be accounted for (pl. 5).

A second possibility, really only a modification of the first, is that the two hanging-wall blocks originally were one thrust plate which was imbricated during thrusting, and the southern part overrode the northern in a slightly more easterly direction. This interpretation would explain the offset in the rhyolite porphyry zone and also the origin of the large slice of schist in the granodiorite (pl. 1). This slice of schist contains part of a rhyolite porphyry sheet, which lies on the projection of the porphyry zone to the northeast and therefore tends to support the interpretation. The attitudes of faults as exposed at the surface do not lend readily to the interpretation, but these attitudes may not be representative of the general attitude at depth of one or either of the faults.

A third possibility with many alternatives is that these faults are not immediately related in origin, except as independent responses to the same general period of compression. The first two possibilities would allow these thrusts to be correlated directly or indirectly with the thrust under Sheep Camp Ridge and Keith Peak and argue for a single basal thrust in the Johnny Lyon Hills area. No positive conclusion can be reached because the fault zones cannot be traced with certainty through the granodiorite mass.

AREA BETWEEN THE JOHNNY LYON HILLS AND KELSEY CANYON

Between the great thrust plates of the Johnny Lyon Hills and the Tertiary rocks of Kelsey Canyon is a large tilted block of Precambrian and Paleozoic rocks analogous in structural position to the Gunnison Hills block and the northeastern less deformed part of the Little Dragoons (pl. 5, block 2). In small exposures north of the American mine the Precambrian rocks of this block have overridden Mesozoic strata (pl. 5, block 4) on a major thrust zone trending north. This thrust zone, which parallels the San Pedro valley, is obviously a line of great structural relief and presumably a structural feature of regional importance. Unfortunately most of the zone is concealed by alluvium, and its relation to the thrusts in the Johnny Lyon Hills is not known.

TILTED BLOCK SOUTH OF KELSEY CANYON

A long eastward-dipping belt of upper Precambrian and Paleozoic rocks is exposed in a series of ridges extending from Tres Alamos Wash south of Deepwell Ranch to the northwestern corner of the map area, a distance of nearly 10 miles. The trend of the belt swings from N. 10° W. at the south end to N. 50° W. south of Kelsey Canyon (pl. 5). The sedimentary rocks rest in angular unconformity on the Pinal schist and the Johnny Lyon granodiorite. To the east they are overlapped by the alluvium of Allen Flat and Tres Alamos Wash, except in the vicinity of Kelsey Canyon where intervening Mesozoic(?) and Tertiary rocks are exposed.

The entire belt has been disjointed by several low-angle faults and a great many steep faults, of which only the larger are shown on the geologic map (pl. 1). The trend of the southern 6 or 7 miles of the belt is the resultant of the strike of the beds and the consistently right-lateral offsets of several different sets of faults. For example, the average strike of the beds in the belt between Tres Alamos Wash and the thrust faults in sec. 27, T. 14 S., R. 21 E., is N. 30° W. but the average trend of the belt over the same distance averages N. 10° W. For several miles north of these thrust faults, the overall trend is N. 35° W., whereas the beds strike N. 55° W.

THRUST FAULTS

At least four low-angle fault zones intersect and offset the stratified rocks in a right-lateral direction. The southernmost zone, a mile south of the Willcox-Cascabel road in the southern part of secs. 26 and 27, T. 14 S., R. 21 E., trends about N. 80° E. and dips 6° to 14° S. The overall offset of the beds is more than 1,000 feet right lateral. An apparently large fault slice, actually only 100 to 150 feet thick, occurs in the zone and consists principally of dragged and locally overturned beds of the Abrigo formation. In the easternmost exposures of bedrock some thin masses of Escabrosa limestone, considerably brecciated, appear in the zone.

The thrust zone probably intersects the granodiorite-schist contact a few hundred yards west of the stratified rocks, but offset of this contact has not been recognized. Exposures are poor, and it must be assumed that fortuitous irregularities in the contact are such as to conceal any offset that exists. Nearly 2 miles to the west a large alteration band in the intrusive rock shows a right-lateral displacement of the proper magnitude by a southward-dipping fault. Furthermore, two smaller alteration bands near the intrusive contact appear to end at about this latitude. (See pl. 1.) There are possible indications therefore of the existence of this fault to the west.

The direction of displacement on this thrust must have been to the west or northwest. The right-lateral displacement could not have been achieved unless the direction of displacement was more westerly than the trend of the formations. Moreover, the nature of drag folds and tear faults in the slices indicates movement in this direction. The displacement evident on the map is clearly minimal. Thrusting in a N. 80° W. direction would require nearly 2,000 feet of movement, and in a N. 40° W. direction more than a mile of movement to create the observed offset.

About three-quarters of a mile to the north, there is a group of southward-dipping low-angle faults, which appear to have been offset by a large normal fault striking N. 30° E. and dipping steeply to the southeast. The overall horizontal separation of beds by these thrusts is right lateral and about 800 feet. Again the evidence points to thrusting from the southeast and the actual displacement may have been much larger than the apparent displacement.

A more conspicuous low-angle fault, about a mile north of the Willcox-Cascabel road, trends about east and dips 40° S. The apparent horizontal displacement of the Pioneer shale is about 1,500 feet, but much of this displacement is contributed by several closely spaced high-angle prethrust faults north of the thrust fault. A more accurate indication of the displacement on the thrust may be obtained from the offset of higher horizons, such as the top of the Martin formation. About 400 feet of right-lateral offset is indicated. The fault cannot be traced in the granodiorite to the west and is offset by a normal fault and lost in the Horquilla limestone on the east. The displacements in this zone are reflected in a corresponding and conspicuous offset in the ridges maintained by the basal part of the Pioneer shale, the Bolsa quartzite, and the Escabrosa limestone.

About a quarter of a mile south of the fault just described, a smaller low-angle fault appears on the crest and dip slope of the main ridge. It offsets the Carboniferous strata nearly 400 feet on the dip slope, but a stratigraphic displacement of only 175 feet is involved. Its gentle southerly dip (about 15°) and right-lateral displacement mark it as a member of the same series as the other low-angle faults in this belt.

South of Kelsey Canyon in sec. 8, T. 14 S., R. 21 E., at least two large low-angle faults appear as segments between younger steep faults that have several trends. The fault pattern is so complex it is not possible to correlate the low-angle fault segments with certainty, but all seem to strike about N. 45° E. and to dip southeast. The northeast strike is different from the nearly east strike of the low-angle faults farther south. The topography gives the traces a general northerly trend. The apparent horizontal displacement of beds on the largest of the faults is variable because of formational thinning, but a minimum of 700 feet in a right-lateral direction is reasonable. As in the case of the faults farther south, the direction of displacement must have been more from the east than the trends of the formations in order to produce the right-lateral displacements. As the bedding has swung to an average strike of N. 50° W. in this latitude the direction of movement must have been nearer west than north.

Further indication that the direction of thrusting may have been more toward the west, and perhaps even southwest, the farther north the fault occurs comes from a fault in the extreme northwest corner of the map area. This fault is partly exposed on the west face of the northeastward dipping Paleozoic section south of Kelsey Canyon in sec. 6, T. 14 S., R. 21 E. Its trace is very sinuous and offset by younger faults. As part of its course is concealed, the interpreted pattern may be part of several faults. The trace of the fault on the topography suggests a gentle dip. The one attitude obtained (dip 58° N.), which is near one of the large offsetting faults, is probably steepened by drag, but there is no indication the direction of dip has been reversed. The relations suggest that the fault is a thrust on which the northern or hanging-wall block has overridden toward the southwest. Parts of the stratigraphic section, including the entire Black Prince limestone, are cut out at various points. This requires that, in general, the northeast dip of the fault should be less steep than the dip of the beds which averages 40° to 45° NE. in most of the section affected.

HIGH-ANGLE FAULTS

High-angle faults, most of which have relatively small displacements, are so abundant in the Paleozoic rocks that they have an important cumulative effect on the structure. These faults generally appear to be contemporaneous with or younger than the thrust faults though there are exceptions. None of the faults could be traced through the older Precambrian rocks.

In the southern 6 or 7 miles of the belt, nearly all the faults are in two general sets, both with predominant right-lateral offsets. The older set trends west to N. 70° W. and dips steeply to the south. The younger set strikes northeast and dips 50° to 65° SE. The older set is generally characterized by larger stratigraphic throws, as much as 300 feet, whereas very few faults of the younger set have throws of more than 100 feet

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Faults of the northwest set at places swing into strike faults and possibly bedding-plane faults in the shale units of the Abrigo and Martin formations. There is a general counterclockwise rotation in the strike of the northeast faults from about N. 55° E. at the south end of the block to N. 20° to 30° E. a mile or two south of Kelsey Canyon. At a few places individual right-lateral faults of the northeast set are joined obliquely by what appear to be complementary left-lateral faults of about the same displacement.

Within 2½ miles of Kelsey Canyon the two sets of right-lateral faults are joined in increasing numbers by eastward-trending left-lateral faults, which dip steeply to the north. Faults of the left-lateral set offset the thrust fault in this area but are in turn offset by right-lateral northeastward-trending faults.

For about a mile south of Kelsey Canyon the fault pattern is far more complex and involves at least four sets of steep faults all younger than the thrust faults. The oldest set, best exposed in sec. 6, T. 14 S., R. 21 E., strikes west to N. 80° W. and dips near vertical, with left-lateral offsets as much as 300 feet or more. The next younger set, also left lateral, trends about N. 35° E. and dips steeply northwest. There are only a few faults in this set, but they have stratigraphic throws as much as 900 feet and are responsible for major offsets of the Paleozoic ridges in secs. 5 and 6. They also offset the Glance(?) conglomerate near the bottom of Kelsey Canyon. Probably younger than these faults are right-lateral faults trending north to N. 15° E. and dipping steeply to the east. They have small displacements, usually less than 100 feet, but are abundant locally.

The youngest high-angle faults near Kelsey Canyon trend N. 65° to 70° W. and cause large right-lateral offsets. They dip 80° to 90° S. and are associated with considerable drag folding where they intersect the Horquilla limestone. The largest of these faults is a mile south of Kelsey Canyon and offsets the Paleozoic section more than 1,700 feet, with a stratigraphic throw of more than 1,000 feet. It is responsible for a conspicuous break and offset in the principal ridge. More than a mile to the west, in the SW¼ sec. 6, a small window in the alluvium reveals granodiorite within 50 feet of the Bolsa quartzite, indicating a large fault which may be the same one.

Two more faults of the N. 65° to 70° W. set, about a quarter of a mile north of the one just described, cut the Horquilla limestone and appear to be responsible for a series of drag folds with nearly horizontal axes. The faults intersect low-angle faults to the west and are lost in the bedding in that complicated area (pl. 1). The drag folding suggests that the faults are of the normal type with the south side down dropped. This is compatible, of course, with the right-lateral apparent displacements. The N. 65° to 70° W. faults are parallel to the Antelope Tank fault (pl. 5). Indeed they may well be part of that fault zone, which probably had a long and complex history.

All the steep faults between the Johnny Lyon Hills and Kelsey Canyon can be interpreted as simple normal faults, but the possibility of a substantial lateral component of movement cannot be precluded in most cases. Lamprophyre sills in the Horquilla limestone are offset by northeastward-trending right-lateral faults. If these lamprophyres, like most of the lamprophyres in the Dragoon quadrangle, are related to the Texas Canyon quartz monzonite, then the most recent faulting is post-early Tertiary. It is also distinctly younger than the age of the thrusting in the Johnny Lyon Hills area.

THRUST FAULTS NORTH OF THE AMERICAN MINE

Near the Western boundary of the Dragoon quadrangle and north of the Willcox-Cascabel road, major faults with general northerly trend and easterly dip are exposed at intervals for a total length of a little more than 1 mile and define the edge of structural block 4 (pl. 5). The trace of the easternmost fault emerges from beneath the alluvium several hundred feet west of the quadrangle and trends northeast, it swings north and northwest before disappearing again beneath the alluvium in sec. 7, T. 14 S., R. 21 E. It brings granodiorite on the east against a slice, about 700 feet wide, of Pinal schist, granodiorite, and deformed masses of Pioneer shale and diabase. In one part of the block, the Pioneer shale is in sedimentary contact on the schist and is overturned to the northeast. There are a number of slivers of quartzite, probably Bolsa, in the fault zone.

The attitude of this fault could be measured at only one point, a wash near an abandoned prospect now known as the American mine, where its dip is 47° SE. Relations at the prospect, which is about 300 feet east of the fault trace, tend to confirm a southeastward dip. At the prospect an inclined shaft with a bearing of S. 68° E. and inclination of 55°, was sunk in the granodiorite of the overthrust plate. The dump consists largely of granodiorite but the last material added came from the Pioneer shale, showing that the workings penetrated the fault. The shaft was entered in the hope of determining the location of the fault in depth, but it was found to be flooded 90 feet below the collar and is in granodiorite to this depth. The workings must be considerably more extensive, perhaps totaling 750 to 1,000 feet judging from the size of the dump. Unless unknown-level working extend to the west, the relations suggest that the fault has a lower dip to the southeast than the 47° measured at the surface. The shaft is inclined in the same general direction as the fault and is only about 10° steeper.

On the west side of the large slice of schist and upper Precambrian rocks is a series of closely spaced thrust faults nearly parallel to the thrust fault on the east side of the slice. Near the north end these faults dip 37° NE. They contain sheared slivers of Pioneer shale, diabase, and Horquilla(?) limestone. In the footwall, in sec. 12, T. 14 S., R. 20 E., a thick section of Walnut Gap volcanics and Glance conglomerate strikes north-northwest and dips east-northeast, apparently overturned. Only a part of the Walnut Gap outcrop is within the Dragoon quadrangle. A quarter of a mile west of the American mine, and just out of the map area, partly exposed plates of limestone of the Naco group rest on red quartzite, shale, and conglomerate of the Morita and Cintura formations. Alluvium conceals the relation of these rocks to the Walnut Gap and Glance formations exposed half a mile to the north.

The relation of these faults and fault blocks is best interpreted by thrusting from the east. The faults dip to the east and successively older formations overlie younger rocks from west to east. Apparent overturning of the thick section of the Walnut Gap and Glance formations also suggests that the eastern blocks overrode the western. Previous thrusting in the opposite direction is perhaps suggested by overturning toward the east of the Pioneer shale in the block between the two principal fault zones.

The stratigraphic throw in this fault zone is very great. A section at least 4,000 feet thick is cut out by the western fault in sec. 12, T. 14 S., R. 20 E.; an indeterminate, but probably great, additional throw is contributed by the eastern fault. The minimum displacement west of the American mine is even greater, as older Precambrian rocks are in fault contact with the Morita and Cintura formations.

MIDDLE TERTIARY TO QUATERNARY DEFORMATIONS

At least two episodes of important block faulting and gentle folding postdate the Galiuro volcanics and are largely responsible for the basins and ranges of the present. One of these deformations preceded and the other followed deposition of the older alluvium. Evidence of one or both of these deformations is conspicuous near the Gunnison Hills and also in the area north of the Antelope Tank fault.

No direct evidence of these late deformations was found in other parts of the quadrangle, but the ranges do transect older structures at many places and probably are in part fault controlled. The ranges in the southwestern half of the quadrangle are deeply eroded as shown by the etching out of softer formations and the development of extensive pediments. Any Basin and Range faults that may exist have long since been bevelled by pediments and buried beneath pediment gravels. It is possible, of course, that Tertiary and Quaternary structures are present in the pre-Tertiary rocks and cannot be distinguished from older structures.

STRUCTURAL FEATURES AFFECTING THE GALIURO VOLCANICS

FOLDS

The Threelinks conglomerate and Galiuro volcanics dip at angles as much as 30°. The main part of the Steele Hills is maintained by a large gentle syncline which plunges N. 50° W. (pl. 1). A small subparallel anticline is evident in the Threelinks conglomerate to the east. About a quarter of a mile north of Antelope Tank, the conglomerate and volcanic rocks roll over to form an anticline with its axis trending about N. 75° W. This trend is distinctly more westerly than the other folds and is nearly parallel to the Antelope Tank fault. The relations suggest that the anticline is a drag effect.

The northeast limb of the Steele Hills syncline extends into the Winchester Mountains where other gentle folds appear. The dips of the volcanic units have been much steepened and locally even overturned in huge landslides which will be described in connection with the development of the topography.

In Kelsey Canyon the Threelinks conglomerate and Galiuro volcanics strike northwest to north and dip east. These units and the same ones in the Winchester Mountains dip toward one another, which suggests an intervening synclinal axis which could well be an extension of the Steele Hills syncline (pl. 5). Available geophysical data suggest that volcanic rocks are present beneath Allen Flat, as required by the synclinal interpretation. The aeromagnetic map of the Dragoon and Cochise quadrangles (U.S. Geol. Survey, 1952) shows that magnetic contours, in a band 1 to 3 miles wide, follow a line between Kelsey Canyon and Antelope Tank and continue with the same trend all the way across the Cochise quadrangle, a total distance of more than 30 miles. The band represents a south-facing magnetic slope which must represent a break in the geology. We suggest that the Antelope Tank fault is the near-surface expression of this break. Presumably the block north of the fault contains volcanic rocks, which have a relatively high magnetic intensity.

FAULTS

Large steep faults that were active in post-Galiuro time trend northwest and include the Antelope Tank fault, Gunnison Hills fault, and two unnamed faults between the Antelope Tank fault and the Winchester Mountains (pl. 1). Most of these major faults strike parallel to the long axes of the mountain ranges, but at least one, the Antelope Tank fault, is oblique to the topographic trend.

The blocks of volcanic rock between the major faults are cut by two fairly conspicuous fault sets, which trend north and northeast respectively; another and older set that trends nearly east is evident in the north wall of Kelsey Canyon (pl. 1). The minor faults, which are mostly normal but in part reverse faults, have indicated throws as much as several hundred feet. No minor faults are known to cut a major fault. The northward-trending fault set, which is conspicuous north of Kelsey Canyon, is not recognizable south of the Antelope Tank fault, suggesting that the minor post-Galiuro faults end at the major breaks.

The Antelope Tank fault, though probably an important regional structure, is not expressed topographically and is nowhere actually exposed. Evidence for the fault and its principal characteristics are summarized in connection with probable Late Cretaceous or early Tertiary movements. The distribution of the Galiuro and Threelinks formations indicates that the north side was downthrown in post-Galiuro time. These movements may have been horizontal and not vertical. If the movement had been vertical, the drag effect near Antelope Tank would have been to steepen the limb of the Steele Hills syncline and not to drag it over into an anticline. In Kelsey Canyon the structural relations in the vicinity of the fault are not well exposed. Near the bottom of the canyon the steeply dipping Glance(?) conglomerate is believed to be in fault contact with more gently dipping Threelinks conglomerate. The exposures are not good enough to permit positive recognition of the fault, but its position is inferred from the general difference in attitude of the two formations and from local steepening, presumably by drag, of the Threelinks conglomerate (pl. 2, section *A–A′*). The direction of apparent drag at this locality is opposite that near Antelope Tank and is compatible with vertical movement. The reason for the difference in post-Galiuro drag phenomena is obscure. At both localities the north side was downthrown.

The amount of post-Galiuro movement on the Antelope Tank fault is indeterminate because the same marker horizons are not exposed on the two sides. The structural relief need not have been very great to yield the observed relations. At some places it may have been less than 1,000 feet, as suggested on section *A–A′* (pl. 2). The fault is not expressed in the present topography, and therefore its movement probably preceded that on faults, such as the Gunnison Hills fault, that are at the edges of the present basins. The Antelope Tank fault is probably nearly vertical and hence would not be much offset by transecting Basin and Range faults, which are characterized by steep dips and nearly dip-slip movements.

The Gunnison Hills fault is the largest Basin and Range fault in the Dragoon quadrangle. It is a normal fault along which the west side appears to have been downthrown about 5,000 feet. As a considerable part of this apparent displacement postdates the older alluvium, detailed discussion of the fault is given in the next section.

Two other northwestward-trending faults, possibly of the Basin and Range type, displace the Galiuro volcanics south of the Winchester Mountains (pl. 5). One of these faults, at the north end of the Steele Hills, trends N. 45° W. and forms the southwestern boundary of the Morita and Cintura formations for nearly 3 miles. The block southwest of the fault has been downthrown a few hundred feet. The Threelinks conglomerate is cut out locally, and, in the southern part of sec. 13, T. 14 S., R. 22 E., older alluvium in the downthrown western block is brought into contact with the Morita and Cintura formations.

Several miles northeast of this fault, a considerable larger but concealed fault is responsible for the outcrops of volcanic rock near the eastern boundary of the Dragoon quadrangle in secs. 4, 5, and 9, T. 14 S., R. 23 E. At two places on the west side of the largest outcrop (in sec. 9), Cretaceous(?) sedimentary rocks are exposed within several hundred feet of the volcanic rocks. The strike of the volcanic rocks is at a large angle to the contact, which therefore must be a fault along which the volcanic rocks were downthrown. The fault evidently extends northwest into the SE¼ sec. 5, but beyond this point its location is not clear. To the southeast it probably extends at least 4 miles beyond the Dragoon quadrangle boundary beneath the alluvium of Sulphur Spring valley. There is another outcrop of volcanic rock in the adjacent Cochise quadrangle, on the common boundary of secs. 15 and 16, that suggests the position of the fault; and beyond this point a conspicuous positive magnetic anomaly (U.S. Geol. Survey, 1952), suggesting the presence of buried volcanic rock, extends approximately as far as Highway 86. The block east of this fault appears to have been downthrown at last 2,000 feet.

AGE OF DEFORMATION

Although some faults that affect the Galiuro volcanics in the Steele Hills area also affect the older alluvium, many of the structural features in the volcanic rocks must have formed during a post-Galiuro prealluvium episode of deformation. Near Kelsey Canyon, the tilting evident in the volcanic rocks is not expressed by a corresponding tilt in the alluvium, nor is the contact of the bedrock and alluvium offset by the faults. At the south end of the Winchester Mountains in secs. 10 and 11, T. 14 S., R. 22 E., the rhyolite member of the volcanic sequence dips about 20° SW. Older alluvium is exposed east and west of the rhyolite and has an anticlinal relation to the homoclinal rhyolite mass. The alluvium on the east has an average dip of 23° E. but on the west 14° W. These relations require at least two periods of deformation, one before and one after the older alluvium was deposited.

STRUCTURAL FEATURES AFFECTING THE OLDER ALLUVIUM

Exposures on the west side of the Winchester Mountains, Steele Hills, and Gunnison Hills reveal that the older alluvium has been tilted upward along the flanks of these blocks. Dips near the older rocks are commonly 10° to 20° W. and locally as much as 30° to 40° W. toward the adjacent basin, but they flatten to several degrees within a mile toward the axis of the basin. At a few places the dip direction is reversed due to minor folds trending northwest. Outcrops of older alluvium are very scarce on the east side of these mountain blocks, but those that have been found reveal dips to the east. The anticlinal structure indicated tends to support a statement by Bryan (1926, p. 170) that mountain blocks in this part of Arizona were pushed up through the less competent valley fill near the end of Tertiary time.

Beds of older alluvium exposed elsewhere in the Dragoon quadrangle are so nearly horizontal that any deviations may be ascribed to initial dip. Some broad warping may have occurred and is even suggested in aerial photographs of the lake beds south of the Johnny Lyon Hills. However, the degree of warping, if any, is too gentle and the reference planes are too indefinite to confirm on the ground without much more work than has been done.

Fault contacts between alluvium and older rocks are exposed at nearly a dozen places in the Steele Hills and at one place in the Gunnison Hills. Under favorable conditions the fault planes are well exposed because of erosion of the alluvium, but more commonly they are bevelled by pediments and are obscure. None could be followed where alluvium is in both walls. The faults trend northeast, north, and northwest. They dip between 60° and 75° and are of the normal type.

Many of the faults are evidently small, but one, the Gunnison Hills fault, appears to be of major importance. This fault is exposed north of Highway 86, where it trends north-northwest, dips about 75° W., and forms the contact of the alluvium and Glance conglomerate for about half a mile. The fault zone is concealed by pediment gravels to the north and south, but we believe it continues along the entire west side of the hills. If our interpretation is correct, the Gunnison Hills block has been uplifted 5,000 feet or more. (pl. 2, section *0–0′*) Some of this uplift, however, may have occurred before the older alluvium was deposited.

The post-older alluvium movement on the Gunnison Hills fault may have been 1,000 feet or more. A water well in the NE¼ sec. 30, T. 15 S., R. 23 E., less than half a mile from the Gunnison Hills block is reported to be 563 feet deep and entirely in alluvium. The top of the hills is 730 feet above the contact of the alluvium and bedrock. These data suggest a minimum postalluvium uplift of about 1,300 feet, provided the hills do not represent an old ridge that was buried by alluvium and subsequently exhumed by erosion. The latter hypothesis requires that the hills have undergone at least two periods of erosion, which seems unlikely. The hills are still youthful topographically. The characteristic topographic expression of the various formations is still not well developed; and the relatively straight fault-controlled west side of the hills is still evident across formations as resistant as the Escabrosa and as nonresistant as the Abrigo, Martin, and Earp.

Aerial photographs of the alluvium show a number of linear features due to vegetation or changes in soil color. Ground checks of these features have generally failed to confirm faulting. One exception is the faults shown west of the Steele Hills in secs. 24 and 25, T. 14 S., R. 22 E. These faults, which are steep and trend N. 5° to 25° W., separate limestone alluvium on the east from volcanic alluvium on the west. The faults are lost where they enter limestone alluvium on the north and volcanic alluvium on the south. Another exception is a series of sheared exposures etched out by erosion in the NW¼ sec. 3, T. 14 S., R. 21 E., north of Kelsey Canyon. The shearing trends about N. 30° W. and dips steeply. It has not been possible to demonstrate any appreciable offsets within the map area and the feature is not shown on the map.

DEVELOPMENT OF THE TOPOGRAPHY

ORIGIN OF THE PRINCIPAL FEATURES

Sulphur Spring valley and San Pedro valley with an intervening highland were developed as topographic features by late Tertiary time, as shown by facies variations in the older alluvium. It has been shown by Meinzer and Kelton (1913, p. 57–58), and Jones and Cushman (1947, p. 8) that buried lake clays occur to a depth of at least 720 feet near the center of the Sulphur Spring valley a few miles east of the Dragoon quadrangle, and these lake deposits interfinger with and grade laterally into stream-deposited sands and gravel that become progressively coarser as the bordering mountains are approached. The studies of Heindl (Halpenny and others, 1952, p. 72) have revealed a similar old lake basin in the San Pedro valley south of the Narrows, which are several miles west of the Johnny Lyon Hills. There is no evidence of an ancient lake in the San Pedro valley between the Narrows and Redington, 24 miles to the northwest, but buried lake clays and silts appear again north of Redington (Halpenny and others, 1952, p. 90–91). Our field observations show that the lake south of the Narrows extended into the southwestern corner of the Dragoon quadrangle. The composition and variation in particle size of the bordering stream deposits indicate bedrock hills in the position of the Little Dragoons and Johnny Lyon Hills and also a volcanic range or ranges to the north.

The composition of the older gravels does not require topographic highs in the Gunnison Hills-Steele Hills area. The Winchester Mountains, Steele Hills, and at least the northern part of the Gunnison Hills were uplifted later, as shown by upturning and faulting of the older alluvium along the west side. Alluvium that was almost certainly derived from the Little Dragoons occurs as erosional remnants in the Steele Hills and Gunnison Hills and forms the intervening ridge for a length of about a mile. If preolder alluvium hills existed in this area, they must have been buried and obliterated as topographic features before deposition of the older alluvium ceased. The present hills reflect more recently uplifted blocks modified by erosion. This interpretation agrees with the conclusion of Bryan (1926, p. 169) that the mountains of the San Pedro valley are residual elevations from uplift that involved the Gila conglomerate.

The details of topography immediately after the post-Gila uplift may have been considerably different from the present, for the effects of subsequent stream erosion have been great. These effects were controlled by local base levels determined by the San Pedro River and the Willcox playa and by the structure and relative resistance of the various formations.

The Willcox playa, which forms the base level to the east, is in the center of a closed basin probably in existence since Tertiary time. Rock debris washed into the basin must have caused a gradual rise in its elevation unless counterbalanced by earth movements of which there is no direct evidence. Sediment is being deposited on the playa and the lower part of the surrounding alluvial slopes, which are inclined 15 to about 50 feet per mile toward the playa. Nearer the mountains the surface of deposition grades without a topographic break into a surface of erosion on older alluvium and the underlying bedrock. This erosional surface, which slopes between 50 and 200 feet per mile, is conspicuous near Dragoon and in the northwest corner of the Dragoon quadrangle between the Winchester Mountains and the Steele Hills. It is cut for the most part on older alluvium, Threelinks conglomerate, and Cretaceous rocks. Small pediment remnants capped by alluvium rise as much as 100 feet above it near the Winchester Mountains.

The drainage basin of the Willcox playa has expanded westward at the expense of the San Pedro basin. Between the Steele Hills and the Winchester Mountains, tributaries of the playa have relatively steep gradients in their upper parts and by headward erosion are dissecting Allen Flat, which was cut by tributaries of the San Pedro. Perhaps as much as 10 square miles of the San Pedro basin may have been captured in a westward extension of the Willcox basin between the Winchester Mountains and the Steele Hills. Southwest of the Steele Hills, the headwaters of Antelope Wash have also encroached on Allen Flat in an embayment about 1½ miles deep and 3 miles wide. This embayment and the one north of the hills are only 2,000 feet apart at one point northwest of Antelope Tank, suggesting that the entire Steele Hills drainage will be captured ultimately by tributaries of the Willcox playa.

The basins of Walnut Wash and Big Draw probably represent a more advanced stage of piracy than that by Antelope Wash. These basins are maturely dissected, but some residuals extend to the general elevation of Allen Flat. Probably Walnut Wash and Big Draw long ago encroached on and started to dissect the surface cut by tributaries of the San Pedro. The old drainage divide had a nearly straight course from the Steele Hills, through the Gunnison Hills and into the Dragoon Mountains. The divide now turns sharply in the Steele Hills and for 8½ miles has a southwesterly course to Lime Peak in the Little Dragoons, whence it turns more than 90° and takes a southeasterly course into the Dragoon Mountains via Dragoon Pass. Piracy of about 40 square miles is indicated.

It is surprising that drainage to the Willcox playa, which constitutes a rising base level of erosion, should be more aggressive than drainage to the San Pedro River, which is downcutting. The piracy followed cutting of Allen Flat by tributaries of the San Pedro and hence can hardly be explained as a normal development in the evolution of a basin of interior drainage. The relations suggest relatively late subsidence of the Willcox basin due to regional tectonic forces or to loading by sediments. No direct evidence of such subsidence has been reported.

The local base level for the westward-flowing streams is, of course, the San Pedro River. This base level, unlike the one to the east, has evidently been lowered several times by rather abrupt incisions of the river. Bryan (1926; Bryan, and others, 1934) studied these changes and recognized two principal levels of pediments cut by its tributaries. The older and higher surface was called the Tombstone pediment because of its extensive preservation at the base of the Dragoon Mountains near Tombstone and farther south. After rejuvenation of the San Pedro a new lower surface was cut which is called the Whetstone pediment because of its prominence along the northeast face of that range. The geomorphic cycle was once again interrupted and the river cut a new terrace of limited lateral extent called the Arivaipa terrace. Subsequently the river was entrenched below the Arivaipa terrace somewhat deeper than it is at present. After some alluviation a new period of downcutting began at the mouth of the river in 1883, and by 1892 a trench had been cut 125 miles upstream (Bryan, 1925a, p. 342). At present this trench is 10 to 25 feet deep along most of the river.

The pediments recognized by Bryan cannot be traced continuously into the Dragoon quadrangle from the type localities; but according to his map of the physiographic surfaces in the adjacent Benson quadrangle (Gilluly, 1956, pl. 10), the now somewhat dissected surface along the south boundary of the Dragoon quadrangle west of the Dragoon Mountains is the Whetstone pediment. We accept this interpretation because the width, elevation, and slope of this surface are nearly a mirror image of the type Whetstone pediment across the valley, and because on the side toward the river the surface ends in bluffs 100 to 200 feet high whose base is the Arivaipa terrace, which can be traced continuously along the river from its type locality.

No definitely older higher surface equivalent to the Tombstone pediment has been recognized in the Dragoon quadrangle. The principal surfaces cut by the San Pedro drainage are described in the following paragraphs beginning with the surface most distant from the river, where remnants of the Tombstone pediment are most likely to have been preserved.

Allen Flat, at the southwest base of the Winchester Mountains, truncates deformed older alluvium and parts of the Galiuro volcanics. It has an elevation of 5,000 to 5,500 feet next to the mountains and slopes to the southwest 125 feet per mile on the average. It is best developed north of the Willcox-Cascabel road in an area of about 30 square miles. In less perfect form it extends southeastward to the drainage divide into the Willcox basin. It is recognizable for at least 12 miles northwest of the Dragoon quadrangle, in part as the upper surface of mesas.

Allen Flat evidently was cut by the upper tributaries of Tres Alamos Wash. The cutting clearly expresses a geomorphic cycle earlier than the present, but the flat is still forming in the well-preserved part north of the Willcox-Cascabel road, as rejuvenation of Tres Alamos Wash has not yet been transmitted to this part of its basin.

Two tributaries of the San Pedro, Kelsey Canyon Wash and Hot Springs Canyon Wash a few miles to the north, are responsible for deeper dissection of Allen Flat than are tributaries of the Willcox playa. Both these washes have an advantage over Tres Alamos Wash in shorter courses to the San Pedro. For example, water falling on the Kelsey Canyon-Tres Alamos divide near the north boundary of the Dragoon quadrangle has a course of about 10 miles to the San Pedro via Kelsey Canyon but more than 35 miles to the same point (mouth of Kelsey Canyon) via Tres Alamos Wash. The more direct drainage of Kelsey Canyon and Hot Springs Canyon has captured about 50 square miles of the old Tres Alamos basin and has cut youthful valleys commonly several hundred feet deep in the northern part of Allen Flat. The area of piracy and dissection is north of the Dragoon quadrangle except for several square miles near Kelsey Canyon.

On the southeastern side of the Little Dragoons, an old erosional surface that could be the extension of the Allen Flat surface is still evident in the concordant summit elevations of low hills and ridges. The surface was developed on the older alluvium and as an extensive pediment on the older rocks, particularly the Texas Canyon quartz monzonite. It extended into the upper part of Walnut and Sheep Basins and had low relief except for Adams Peak, the high ridge culminating a mile north of the Triangle T Ranch and some other residual hills in interfluvial areas. Many of the residual hills like Adams Peak, were due to resistant rock. According to Bryan (1925b, p. 8) the pedestal rocks in Texas Canyon and Sheep Basin were formed by the destruction of the old pediment and incipient formation of a new pedim nt at a lower level. As the old pediment was destroyed, mechanical and chemical weathering was localized along joints in the quartz monzonite, and the disintegrated rock was removed by running water. In Bryan's interpretation, the pedestal rocks in other granite terranes of the southwest were formed in the same way and were formed only where the new pediment level is 150 feet or less below the old level.

On the west side of the Little Dragoons a dissected erosional surface extends down Tres Alamos valley. The largest and best preserved remnant of this surface, known as the Mesa by local ranchers, is on the west side of the valley south of the Willcox-Cascabel road. It has an extent of about 6 square miles and was cut on the Johnny Lyon granodiorite and Pinal schist; it has an average gradient of about 200 feet per mile to the east toward Tres Alamos Wash. On the east it frays off into a belt of dissection near Tres Alamos Wash. The western limit is in part the Johnny Lyon Hills and in part an irregular northward-trending escarpment localized for most of its length by a zone of shearing and alteration in the granodiorite. The escarpment is about 150 feet high and separates the Mesa from a lower pediment, known locally as the River Slope.

The River Slope was cut on the Johnny Lyon granodiorite and older alluvium and has an average gradient of about 300 feet per mile to the west toward the San Pedro River. It ends 2 to 4 miles west of the Dragoon quadrangle at the Arivaipa terrace. Between the Johnny Lyon Hills and an irregular line, 1½ miles or less, north of the Willcox-Cascabel road, the River Slope has very low relief except near the San Pedro where recent incision of the river has rejuvenated the washes. The upper part of the slope is still developing. Recent capture of the Mesa drainage by the River Slope drainage is evident along two washes south of the Willcox-Cascabel road. In addition to headward erosion, the washes are continually stripping and regrading the surface. Low bedrock residuals capped by alluvium are found in some interfluvial areas. These features, also noted on some of the higher surfaces, clearly indicate regrading which may be a normal late-stage "policing" action on pediments.

West of the Johnny Lyon Hills, the continuity of the River Slope is broken by later erosion, but it seems to have continued to the south and to have merged with the surface in Tres Alamos valley. This latter surface in turn seems to merge with the old surface in Texas Canyon and also with the one mapped by Bryan as the Whetstone pediment in the northeastern part of the Benson quadrangle. As the surface in Tres Alamos valley and the one in Texas Canyon both seem to merge with Allen Flat, our data require only one major cycle of erosion after the post-Gila uplift and before the Arivaipa terrace cycle. More than one cycle could be represented in this interval because later dissection makes the correlation of surfaces uncertain. The abrupt escarpment separating the River Slope from the Mesa north of the Johnny Lyon Hills reflects a difference in the length of drainage courses to the San Pedro River. The washes that cut the River Slope are 4 to 6 miles long, whereas those that cut the Mesa had to flow 20 miles or more to reach the same points on the river. It is not necessary to call on two cycles of erosion to explain the escarpment, for in a single-cycle origin the Mesa would inevitably be higher.

Incision of the San Pedro River to the Arivaipa terrace level rejuvenated its tributaries and started a period of rapid dissection that has continued to the present. Tres Alamos Wash has developed a narrow flood plain graded to the Arivaipa terrace between its mouth and the approximate latitude of Lime Peak. This part of the stream is incised 150 to 250 feet below nearby remnants of the old erosional surface. Other streams in the Dragoon quadrangle are in a more youthful stage of development and are not so deeply incised. Nevertheless the effects of the Arivaipa terrace cycle are conspicuous in the southwestern half of the quadrangle except on the Mesa and part of the River Slope. Rejuvenation of Tres Alamos Wash has been only weakly transmitted to Allen Flat as yet, but Kelsey Canyon is rapidly dissecting this area. The effects of post-Arivaipa terrace incisions of the San Pedro River do not appear to have reached the Dragoon quadrangle yet.

LANDSLIDES IN THE WINCHESTER MOUNTAINS AND STEELE HILLS

After the topography had developed very much as it is today, great masses of the Galiuro volcanics broke away from the steep southeastern end of the Winchester Mountains and slid southward and southwestward into Sulphur Spring valley over the underlying Threelinks conglomerate and Cretaceous(?) rocks. Some slides were as much as half a mile wide and moved more than half a mile into the valley. The occurrence of one slide on top of another indicates that sliding was repeated. The older and larger slides have been much eroded and are now represented by erosional remnants capping low foothills. The original extent of these slides is uncertain. Several landslide remnants preserved on the east side of the Steele Hills represent parts of a single slide that moved eastward from the ridge crest over the Threelinks conglomerate and the Morita and Cintura formations undivided. The slides in both the Winchester Mountains and Steele Hills are shown on the geologic map (pl. 1, pl. 2, section *J–J′*).

Wherever the attitude of the rocks has been determined in the slides, a sharp backward tilting toward the source is evident. Thus in the Steele Hills the rhyolite in place dips about 15° W., but in the landslide remnants dip 60° W. to vertical. In the Winchester Mountains the andesite and latite above the slides dip about 15° N. The angle of dip in the slides is as much as vertical and is overturned at a few places. The rotation took place because the base of the slide is a curved surface that is concave upward. The direction and amount of rotation were determined by the direction and curvature of the surface of sliding.

Geologic mapping indicates that the base of several slides approaches the horizontal at the outer edge but steepens as the source is approached. The upper part is invariably eroded or concealed by recent talus from the cliffs above, but the topography requires still further steepening upward. The top of the surface of sliding may have been near the vertical.

Varying degrees of disruption are evident in different slides and in different parts of the same slide. Comparatively little disruption has taken place in two of the western slides in the Winchester Mountains. Although considerable shattering is evident in these slides, dislocations of the steep-dipping depositional contact of the latite member on the andesite member are limited to small transverse faults. These may be tear faults formed at the time of sliding or segments of older faults that have their continuation in the parent cliff north of the mapped area. Most parts of the slides are much more broken than this. Generally the rock is broken into blocks a few feet to a few score of feet across, which are shifted about with respect to one another. It is generally possible to trace lithologic units by the distribution of the dislocated blocks; but at some places the blocks are so mixed that this is impossible. Mixing of blocks is greatest around the margins of the slides.

Only one exposure of the base of a landslide was found (NE¼SE¼ sec. 6, T. 14 S., R. 23 E.). At this locality, tuffaceous sandstone of Cretaceous(?) age is truncated by 6 feet of breccia; angular fragments as much as 4 feet in diameter of all the lithologic units in the slide block are embedded in a matrix of yellow sandy clay.

Generally the Galiuro volcanics are the only rocks exposed in the slides, but at several places part of the underlying Threelinks conglomerate is involved. The presence of the relatively incompetent conglomerate below the competent volcanic rocks is probably the basic cause of the slides. The conglomerate is easily eroded and causes the volcanic rocks to stand in steep and somewhat unstable slopes. The rupture beneath the largest slides passed through the conglomerate and curved upward through the volcanic rock. After the mass left its original position it moved out over the land surface then existing below it. Conditions for landsliding were more favorable where the base of the Galiuro volcanics was at a relatively high elevation on a steep slope. The depth of erosion since the oldest slides indicates considerable age, but all the slides now preserved probably were formed in Recent time.

IGNEOUS METAMORPHISM OF THE CARBONATE ROCKS

Igneous metamorphism in its broadest sense includes all rock alteration due to heat and fluid emanations from a magmatic source. Alteration of this kind is conspicuous around the large masses of intrusive igneous rock in the Dragoon quadrangle, and it is perceptible adjacent to some of the small bodies. Many of the effects have been mentioned in the description of the rock formations. Data bearing on the metamorphism of carbonate and associated clastic sedimentary rocks in the vicinity of the Texas Canyon quartz monzonite have been brought together in an earlier report (Cooper, 1957) from the point of view of the processes involved, rather than the particular formation affected. The underlying objective was to determine what it is reasonable to infer concerning the cause and localization of the alteration, including the valuable metallic mineralization that was an integral part of it.

Some conclusions reached in this earlier study will be summarized here. The reader is referred to the original paper (Cooper, 1957) for details and supporting evidence.

Carbonate rocks in the Paleozoic and Mesozoic formations are metamorphosed in the vicinity of the Texas Canyon stock, particularly on the northeast side, where metamorphic effects are discernible at the northern end of the Gunnison Hills as much as 3 miles from the intrusive body as exposed. The grade of metamorphism increases inward toward the stock.

Although clearly related in space to the Texas Canyon quartz monzonite, much or all of the metamorphism followed intrusion of a lamprophyre dike, whose unaltered parts are identical petrographically to dikes that have intruded and chilled against the quartz monzonite (Cooper, 1957, p. 593–594). Apparently the exposed parts of the quartz monzonite were solidified, fractured, and injected by lamprophyre before metamorphism took place.

In the vicinity of Johnson, the matamorphosed carbonate rocks show successive zones characterized by (1) chlorite (locally talc), (2) tremolite, (3) forsterite and diopside, and (4) garnet (with local wollastonite and idocrase) as the stock is approached. The mineralogical and textural changes indicate an origin of the silicate minerals by a fixed sequence of chemical reactions between original constituents of the sedimentary rock, with a negligible amount of material added from an outside source but with some interchange of material between beds. Silicate minerals generally did not form in pure carbonate rocks in any zone. The distinctive silicates of the outer three zones formed in abundance only in impure dolomite. Garnet, wollastonite, and idocrase of zone 4 formed only in impure limestone; the mineral assemblages in the once dolomitic rocks remained the same in zone 4 as in zone 3.

The chemical reactions that can reasonably be inferred (Cooper, 1957, p. 582–591) release carbon dioxide and result in the formation of denser minerals. This suggests a decrease in volume, which is confirmed by stratigraphic measurements showing that the silicated facies is as much as 30 percent thinner than the unsilicated facies (Cooper, 1957, p. 595–597). Structural features resulting from the loss in volume are very obscure because of greater deformation not due to the metamorphism and because of recrystallization during the metamorphic process.

The sequence of reactions that evidently took place in the siliceous dolomite and limestone near Johnson are generally the same as the equilibrium sequence proposed by Bowen (1940) and Tilley (1948), as modified by later experimental work of Harker and Tuttle (1955, 1956) and theoretical equilibrium curves of Weeks (1956, fig. 4). If ore and late-stage retrogressive minerals are disregarded, the equilibrium mineral assemblages predicted for any composition by means of this series of reactions generally occur in beds of that composition. Certain perculiar facts of mineral association, such as the occurrence in zones 3 and 4 of calcite-tremolite, calcite-forsterite, and diopside rocks close to one another are explained by nonadditive metamorphism and do not require local lack of equilibrium or any other special conditions. Variations in the amount of quartz in the original rock can explain the three assemblages (Cooper, 1957, p. 582–588).

The formation of garnet in argillaceous and feldspathic limestone involved several reactions, including a reaction between orthoclase and calcite to form grossularite, quartz, and a solution of K_2O and CO_2 that was expelled from the rock (Cooper, 1957, p. 589, 606). This reaction, which is not yet widely known by geologists, provides a possible source of potassium in hydrothermal solutions.

The principal exceptions to the general nonadditive character of the silication process occur in and near the Republic mine at Johnson, beneath a large low-angle fault, the Republic fault. Here calcareous beds of the middle member of the Abrigo formation have been converted locally to the mineral assemblages normally derived from the siliceous dolomite; and shale beds of the lower member of the Abrigo formation have been locally converted to garnetite instead of to the normal biotite hornfels (Cooper, 1957, p. 590–592). These abnormal effects were probably caused in some unknown way by the more vigorous passage of solutions through the broken rock beneath the fault.

Copper and zinc ore bodies were formed later and at lower temperatures than the general metamorphism of the host rock. The ore minerals—which include chalcopyrite, sphalerite, pyrite, scheelite, a little magnetite, and molybdenite—are intimately associated with small amounts of calcite, actinolite, chlorite, and in places quartz and traces of fluorite and biotite. These minerals are generally interstitial to the garnet, diopside, wollastonite, and other high-temperature minerals of the metamorphic stage, but they have also veined and replaced these older minerals. Fracturing, before and during metalization is indicated (Cooper, 1957, p. 592).

The known ore is in metamorphic zone 4, and most of it is in garnetized beds at the top of the middle member of the Abrigo formation (unit 5 and in places unit 4). Some, but not all, of the ore bodies are at or near the limestone side of garnetite masses, that is where garnetite passes laterally into ungarnetized rock. The ore is generally banded parallel to the beds, for sulfides and associated minerals are generally concentrated in layers 2 to 12 inches thich separated by barren garnetite layers of about the same thickness. The barren layers are the metamorphosed equivalent of clastic beds for they pass locally into hornfels of the kind formed from these beds. Baker (1953, p. 1275) noted that "* * * at the edges of ore bodies sulphide bands often grade into ungarnetized limestone, while the intervening garnetite bands continue several feet or yards beyond the ends of the sulphide bands." This distribution confirms that the sulfide-rich layers represent original beds of limestone and suggested to Baker that these beds were not thoroughly garnetized. Interstitial calcite remaining in the garnet probably localized a large part of the ore.

The gangue minerals formed during metalization seem to be richer in iron than those formed during the progressive metamorphism but otherwise suggest reversal of reactions that took place during metamorphism. All the reactions of the metamorphic stage are reversible. They proceed in one direction when the temperature rises into the stability field of the high-temperature mineral assemblage. When the temperature falls into the stability field of the lower temperature assemblage, the reaction must be reversed, provided sufficient carbon dioxide is available (Bowen, 1940, p. 265–266). Lack of carbon dioxide is the main reason why the reactions are seldom reversed in igneous contact zones.

Late-stage retrogressive effects are not confined to the immediate vicinity of ore bodies but are found in small amounts in almost every thin section of the silicated rock. The late minerals include calcite, quartz, actinolite, chlorite, and commonly small amounts of copper and zinc sulfides. These minerals either pervade the rock along cracks and grain boundaries or are concentrated in tiny spots. The latter habit is particularly characteristic of the "white tactite" (silicated siliceous dolomite) which is marked in many drill cores by scattered gray spots several millimeters in diameter consisting of calcite, actinolite, sulfides, and in some cases quartz, chlorite, and fluorite.

Narrow metalized quartz veins have filled fissures in the metamorphic rock and localized retrogressive effects in their walls (Cooper, 1957, p. 593). In addition to quartz of several generations, the veins very commonly contain potassium feldspar and small amounts of fluorite, calcite, pyrite, chalcopyrite, and bornite. Sphalerite, galena, argentiferous tetrahedrite, and scheelite have been found in them; near the surface supergene limonite, copper carbonates, chalcocite, and wulfenite occur. The veins contain abundant hypogene sulfides only where they cut bedded replacement ore bodies and near such intersections. Because of this fact and because the veins contain galena and tetrahedrite which are not present in the replacement bodies, the veins are regarded as younger and therefore not feeders.

Chemical data interpreted in the light of the evident loss in volume during metamorphism indicate that immense amounts of CO_2 were invariably lost during progressive metamorphism, but the only other constituents consistently gained or lost are minor constituents and the increments are very small. The principal rock-forming constituents, other than CO_2 and K_2O, tend to be lost or gained depending on whether they occur in relatively large or relatively small amounts compared with the immediately adjacent beds, suggesting an interchange of constituents across contacts, as inferred from the geologic evidence. Most of the material involved in the interchange probably moved only a few inches or a few feet, but some constituents like K_2O, SiO_2, and CaO appear to have moved tens or even hundreds of feet. The CO_2 and possibly small amounts of other constituents moved out of the aureole of metamorphic rocks.

In summary, it seems clear that the temperature rose and then fell during the alteration process. While the temperature was rising, large masses of rock underwent progressive and mainly nonadditive metamorphism, which resulted in substantial loss in volume. Metalization started near the temperature maximum, but most metalization, related weak but pervasive metasomatism, and vein filling took place during the time of falling temperature.

The original source of heat energy and perhaps later of substance was probably the Texas Canyon quartz monzonite. Heat was transferred by fluids rather than conduction because (1) the metamorphism and metalization probably took place after the upper part of the quartz monzonite mass had solidified, and (2) beds at Johnson at least 1,000 feet from the stock and 2,000 to 8,000 feet from the nearest known contact were more intensely altered than the same beds in actual contact with the stock in other parts of its periphery.

Little is known of the nature of the fluids and their behavior although some tentative conclusions and speculations can be made (Cooper, 1957, p. 608–609). One thing seems clear. The CO_2 expelled from the rocks in immense quantities during progressive metamorphism was important in the overall process. Though magmatic emanations provided heat for the metamorphic reactions, which are endothermic, the CO_2 expelled at high temperature was a factor in transporting and distributing heat and in causing reactions at higher levels. It was probably also a factor in the solution, transportation, and intergranular diffusion of material. Under the physical conditions of metamorphism, the CO_2 was probably a dense gas with practically unknown solvent properties (Garrels and Richter, 1955). In solution in the magmatic emanations, it may have increased their power to hold ore metals in solution, for ore minerals were not deposited in quantity until the temperature started to fall and expulsion of CO_2 diminished.

By ore-forming time less heat was supplied from below than was being dissipated toward the surface. Carbon dioxide ceased to form locally—at least in large quantities—and the regimen changed. Hypogene solutions probably continued to arise, and these solutions may have been richer in sulfur and base metals than they had been previously. In any event they were able to attack the previously metamorphosed rock and replace it with ore and retrogressive gangue minerals. The factors that localized ore bodies were stratigraphic (certain favorable beds, of which unit 5 of the Abrigo formation is the outstanding example), metamorphic (garnetite facies), and structural (fissures or other structural features that channelized metalizing solutions). These factors are discussed in detail in a later section of this report.

MINERAL DEPOSITS

GENERAL FEATURES

The Dragoon quadrangle, which is the most productive part of the Cochise mining district, has yielded fairly large amounts of copper and zinc, moderate amounts of tungsten, and a little lead, silver, gold, and marble. The principal ore deposits are in and near the Texas Canyon quartz monzonite stock.

Copper and zinc replacement deposits near Johnson had yielded, by the end of 1959, about 1,130,000 tons of ore with a value of about $25,600,000. These deposits are of the pyrometasomatic type. The ore minerals are sphalerite, chalcopyrite, and locally bornite. These minerals, associated with some pyrite, a little scheelite, and traces of molybdenite have replaced favorable beds of metamorphosed limestone of Paleozoic age near fissures and other structures that provided channels for mineralizing solutions. The principal ore bodies have the form of tabular masses and chimneys in the plane of the beds. More than 95 percent of the ore produced has come from such bodies in garnetite derived from the middle member of the Abrigo formation.

Indications of copper mineralization, similar in general to that near Johnson, are found at other places near the Texas Canyon stock. These showings have been extensively prospected and small shipments have been made from the Centurion mine and from several properties west of Dragoon. The total production is probably less than 2,000 tons of ore, most of which was too low grade to make the operations profitable.

Tungsten-bearing veins, lodes, and placers in and near the northeastern half of the Texas Canyon stock were extensively worked between 1898 and 1918; they have been sporadically worked since 1940. The production is not recorded but may have been as much as 75,000 units of tungsten trioxide. The veins trend northeast and consist of huebnerite, scheelite, and traces of base-metal sulfides in a gangue of quartz, muscovite, and fluorite. The most productive deposits are in and associated with the Bluebird vein system which extends from the intrusive contact south of Johnson southwestward for 3½ miles, where it dies out. Rich ore pockets were mined from shallow workings in this and other vein systems, but the veins have proved too small and the tungsten content too erratic for profitable deep mining. At the Tungsten King mine on the west side of the Little Dragoon Mountains, scheelite ore has been mined from a low-grade contact vein between the Tungsten King granite and the Pinal schist; reported production to 1954 was about 12 tons of scheelite concentrates.

Small lead-silver vein and replacement deposits occur in the northern part of the Gunnison Hills. The richest and almost the only productive deposit is at the Texas Arizona mine, which between 1908 and 1928 yielded 718 tons of ore averaging nearly 40 percent lead and 50 ounces of silver to the ton. These ores occurred as small replacement bodies along beds and fissures in the Escabrosa limestone and were oxidized.

Several unconfirmed shipments of gold ore have been reported from the Yellowstone district in the Johnny Lyon Hills area; and shipments of a few carloads of siliceous silver ore are reported from the Winchester district in the Winchester Mountains just north of the Dragoon quadrangle.

Marble, in the form of rough monumental stone, terrazzo, and roof chips, is produced at the Ligier quarries near Dragoon. Operations to date have been on a small scale.

HISTORY OF MINING

COPPER AND ZINC

According to Dinsmore (1909, p. 833–834), the copper deposits near Johnson were worked in a primitive way by Mexican miners before the Southern Pacific Railroad was completed in 1881. The railroad was a great impetus to mining, and before the end of 1882 many claims in the area had been patented, including the Peabody, Republic, and Mammoth claims.

The owners of the Peabody claim, the Russell Gold and Silver Mining Co. of Philadelphia, erected a small smelter at what came to be known as Russellville, which is about 2 miles southwest of the mineralized area and is the nearest point where a permanent water supply was obtainable. In 1883 a pipeline was laid from Russellville to the Peabody mine and the smelter was moved there. Hamilton (1883, p. 87) wrote that the mine was "thoroughly opened by shafts, drifts, levels, etc.," that the smelter had been in operation for more than a year, and that regular shipments of bullion were being made. Dinsmore (1909, p. 833–834) reported that more than $1 million was produced during the eighties, before the mine was declared worked out at a depth of a little more than 150 feet and was closed. This estimate of production is probably exaggerated as the slag dumps from this early operation indicate that only about ten thousand tons of ore were smelted. The grade of ore mined from the Peabody prior to 1902 is not known, but that subsequently mined has averaged 7.4 percent copper and 4.2 ounces of silver per ton. This is considerably below the grade required by Dinsmore's estimate.

After the Peabody mine was closed some time in the eighties, there was apparently no activity in the district until the late nineties when Messrs. A. H. Wien and T. K. Mitchell did extensive prospecting and made some small shipments of ore.[9] About 1900 the high price of copper resulted in a short-lived mining boom during which the Little Dragoon Mountains were prospected by many individuals and small companies. The tungsten deposits were discovered in 1898, and by 1902 most of the copper and tungsten showings of the area had been discovered and explored by pits and shafts.

In 1899 the Dragoon Mining Co., a subsidiary of the Federal Copper Co. of New York, purchased the Peabody mine and reopened it, employing as many as 200 Mexican miners. Oxidized copper-silver ore of a reported value between $250,000 and $1,000,000 was

[9] This and many other details of the history since 1898 have been obtained from the files of the Willcox "Star" (now "Range News").

shipped between 1899 and 1903 when the company failed. According to Dinsmore (1909, p. 833–834) the mine was still less than 300 feet deep. The subsequent production from the mine is dwarfed by that from other mines, although the Bonanza Belt Copper Co., organized in 1907, and its successor, the Peabody Consolidated Copper Co., shipped 14,200 tons of ore containing 2,138,000 pounds of copper and 57,000 ounces of silver in 1907–18. The mine, idle since 1918, was owned in 1957 by the Coronado Copper and Zinc Co.

The Black Prince Copper Co., formed by Denver capitalists in 1901 with Hugh Mackay as president, was an important factor in the development of the district, even though the company produced very little ore. By 1903 it controlled a compact group of 28 claims southwest of the Peabody mine and was doing fairly extensive development work at the Republic and Mammoth mines, as well as in several other parts of its holdings. The objective seems to have been to find a large body of ore, and only development ore was shipped. The company disposed of the Republic and Mammoth mines after a year or two and concentrated its activities on the ground between the Peabody and Mammoth mines, where, in 1905–11, the Black Prince vertical shaft was sunk to a depth of nearly a thousand feet. No ore was found in the shaft or in a crosscut from it. In 1912–18, 1,370 tons of high-grade oxidized ore was shipped from shallow workings near the shaft. The Black Prince group of eight patented claims was purchased in 1949 by the Coronado Copper and Zinc Co.

The Republic and Mammoth mines have had common ownership at least since 1900, by which time they were developed by surface cuts and shallow inclined shafts down the dip of outcropping ore bodies. In 1903 the Black Prince Copper Co. extended the Mammoth shaft to 270 feet and the Republic shaft to more than 160 feet and cut a number of levels at both mines. This work developed a small tonnage of both oxide and sulfide ore; the transition from oxide to sulfide ore is said to have occurred at a depth of 50 to 150 feet. The mines were ripe for small-scale operations; and by 1905 the Arizona Consolidated Mining Co., formed by Philadelphia capitalists, was operating both mines. In the same year, the Arizona and Michigan Development Co., formed by the owners of a smelter in Benson,[10] purchased the Copper Chief mine from A. H. Wien, who had held it since the late nineties.

Both the Arizona Consolidated and the Arizona and Michigan faced a serious problem in the fact that their ore was lower grade than that at the Peabody mine and would scarcely justify transportation expenses, including that of wagon haulage to the railroad. The two companies sought different solutions, the Arizona and Michigan interests promoted a branch railroad to the mines, and the Arizona Consolidated interests built a smelter at the Republic mine.

In 1906 the Johnson Dragoon and Northern Railroad Co., formed by the same interests as the Arizona and Michigan Development Co., started constructing a standard-gage railroad between Johnson and the Southern Pacific tracks at Dragoon. The railroad was completed in November 1909, but it was little used prior to World War I. During the war years it was a major factor in the successful operation of a number of mines. The heyday was reached in 1916, when more than 80,000 tons of ore was shipped from the Republic and 4 or 5 smaller mines, and Johnson had a population of perhaps 1,000. The town included half a dozen business houses and several pool halls and boarding houses. When the Republic mine closed in 1920, the railroad fell into disuse and the tracks were removed in 1925.

The Arizona Consolidated Mining Co. shipped about 12,000 tons of ore from the Republic and Mammoth mines in 1905–07. In 1909 the company was reorganized as the Arizona United Mining Co. and constructed a 125-ton smelter at the Republic mine to treat the low-grade sulfide ore. The smelter went into operation in 1909 but was soon abandoned because certain necessary fluxing ores were not available. The company continued to make intermittent small shipments of ore during 1909–13, but the most important event in this period was the discovery of the Main Manto ore body at the Republic mine, a much larger ore body than any previously found in the district.

The Main Manto ore body nowhere reached the surface. Its discovery was due to perseverance, faith, and luck, coupled with the good judgment of the mine superintendent, J. M. Libbey. The exposed bedded ore bodies at the mine had ended above the 300 level, but the inclined shaft had been extended to the 700 level in spite of the fact that drifts and crosscuts at the 300 and 500 levels had found only a few stringers of ore. About 90 feet below the 500 level the shaft went through the Republic fault, below which it was in beds 300 feet or more below the ore horizon stratigraphically. There is no evidence that anyone at the time, or for many years afterward, realized the direction and amount of the fault movement although Mr. Libbey may have suspected it.

The company was discouraged and weakened financially by the unsuccessful smelter and deep exploration projects but decided to make a final attempt to find ore on the 700 level before closing the mine (John Walker,

[10] The Benson copper smelter, constructed 1902–05 by the Southwestern Smelting and Refining Co., apparently was never operated. Some work was done on it as late as 1919.

oral communication, 1949). The officials at the head office in Philadelphia had long held the geologic opinion that the best chances of finding ore were in the footwall in or near a supposed porphyry in that direction. An old map in the possession of the Coronado Copper and Zinc Co. shows the hornfels derived from the lower shale member of the Abrigo formation as "porphyry"; another possible objective was the Precambrian diabase sill, called the "birds-eye porphyry" by some prospectors in the Johnson area. To explore the "porphyry" area crosscuts on the 300 and 500 levels had been driven into the footwall (pls. 8, 10) and Mr. Libbey was instructed to drive a long crosscut into the footwall on the 700 level. Mr. Libbey drove the crosscut (now caved) and also, on his own initiative, drove another crosscut northeastward into the hanging wall. The head office of the company was never enthusiastic about the latter project, and at the time it struck the Manto ore body in 1912 the miners were working without wages other than room and board (John Walker, oral communication, 1949).

With the outbreak of World War I and the subsequent rise in the price of copper, the Main Manto ore body became attractive for mining, but the Arizona United Mining Co. was too weak financially to capitalize on it. Early in 1914, all the Arizona United property at Johnson was leased to the Cobriza Mines Development Co., a leasing concern controlled by the Goodrich-Lockhart Co. of New York. The Cobriza Co. also leased the Johnson Dragoon and Northern Railroad and began shipping 1,000 to 5,500 tons of ore per month, mostly from the Republic mine but in part from the Mammoth mine. The operation was so profitable that the Arizona United Mining Co. bought out the Cobriza interest in 1918 and began operating it for itself.

Other mines were also active during the war years. The Cooper Chief mine, operated by the Arizona and Michigan Development Co., had its main productive life during this period and yielded nearly a tenth as much ore as the Arizona United property; the Peabody mine continued to contribute appreciably to the total production. A small amount of copper was obtained from the Keystone, Black Prince, and Johnson Copper Development groups of claims, and from the Centurion mine. It is probable that small unrecorded shipments were made from other properties.

The fall in the price of copper in 1920 forced all the mines to suspend operations and for 20 years thereafter there was almost no mining in the district. The Republic mine soon filled with water to a few feet below the 700 level, where the water stood until it was pumped out in 1942. The town of Johnson disappeared except for a few buildings.

There were significant property transactions during the 1920–40 period. The Keystone Mining Co., which had made small ore shipments during the war years, built a 200-ton flotation concentrator on its property in 1920–25. The concentrator was operated for a short test run in 1925, but has been idle since that time. The Arizona United Mining Co. and the Dragoon Mountain Mining Co., which then owned the Copper Chief mine, were merged in 1923 as the Arizona United Development Co. This company later gained control of the Peabody mine. As a result of these transactions, the Arizona United property included all the large mines, and also a large continuous block of ground in the most productive part of the district, the Republic-Copper Chief-Mammoth belt.

The period that Johnson was a ghost camp was marked by great advances in the selective flotation of ores—a technique of potential importance to the district as it provided a means for profitable recovery of the zinc contained in the ore. For the early operators, zinc was a liability for which a penalty had to be paid to the smelters. In 1939 the American Metal Co. made a lease and option agreement with the Arizona United Development Co. Geologic maps of the surface and some of the mine workings were made, and seven diamond-drill holes were drilled. The American Metal Co. gave up its interest about the end of 1940. In 1941 W. A. Hooton of Tucson took a lease and option on the property and began shipping ore on a small scale from the Republic mine. In 1942 some of his ore was shipped to the Shattuck-Denn custom concentrator at Bisbee, and there, for the first time, ores from the district were treated by selective flotation.

In 1942 the Coronado Copper and Zinc Co., controlled by the H. S. Mudd interests of Los Angeles, took over Mr. Hooton's lease and option, with the arrangement that Mr. Hooton could continue mining until August 1, 1945, provided he would operate at the Mammoth rather than at the Republic mine. This he and his successor, Mr. Nicholas Duyn, did. The Coronado Copper and Zinc Co. dewatered the lower levels of the Republic mine and, after considerable exploratory work, purchased the property outright.

After purchasing the property, the Coronado Copper and Zinc Co. built a selective flotation concentrator with capacity of 200 tons per day at the Republic mine and also a small company town in the vicinity. An adequate water supply was obtained by drilling a well in Sulphur Spring valley, 8½ miles east of the mine. Power for pumping, mining, and milling was obtained by building a 9½-mile powerline to connect with the REA system in the Sulphur Spring valley. The mill went into operation in May 1945. From that time until 1957, operations were continuous except for one year, July 1949 to July 1950, when all operations in the district were suspended because of low metal prices. Two concentrates—a copper concentrate and a zinc concentrate—were produced and trucked to Dragoon for shipment to smelters. Between 2 and 3 pounds of zinc was produced for each pound of copper. Some ores that had a relatively high content of copper but low content of zinc were shipped direct to copper smelters. In 1957 operations were again suspended because of low metal prices.

The Coronado Copper and Zinc Co. has operated three mines in the district. Operations started at the Republic mine and continued there until 1952 when the mine was shut down because of exhaustion of known ore bodies. The Mammoth mine was operated until 1949. A large ore body, now known as the A ore body of the Moore mine, was discovered in 1947 about a thousand feet east of the Mammoth mine by exploratory diamond drilling from the surface. The new Moore shaft was started about a year later, and production from the A ore body started in 1951. After the closing of the Republic mine, the Moore mine was the only producing mine in the district through 1957.

Except for the St. George claim, owned by F. M. Lebold and S. N. Lebold, of Chicago, the productive copper-zinc area at Johnson was held in 1955 by two property holders, the Keystone Copper Mining Co., of Dragoon, and the Coronado Copper and Zinc Co. The Coronado property extended northwestward continuously from near the Hagerman and O. K. shafts to include the Mayflower, Republic, Copper Chief, Mammoth, Black Prince, Johnson Copper Development, Mackay, and Peabody workings. (See pl. 6.) The Mayflower, Black Prince, Johnson Copper Development, and Mackay properties were not part of the old Arizona United group but were purchased by the Coronado Copper and Zinc Co. after 1945. The Keystone property adjoined the Coronado property on the southeast and included the Hagerman, O. K., and many smaller workings. The property also included the Peacock group of claims, the ownership of which was long in litigation but was settled in favor of the company (N. M. Rehg, president, Keystone Mining Co., oral communication, 1954).

LEAD AND SILVER

Lead-silver ore appears to have been discovered in the Gunnison Hills about the time the Southern Pacific Railroad was completed in 1881. According to Mr. Cornelius Chambers (oral communication, 1949) of Willcox, two carloads of oxidized lead ore were shipped in the eighties from an opencut on the site of what is now known as the Texas Arizona mine. The deposits were then abandoned and apparently forgotten until rediscovered by B. X. Williams in 1908. The Texas Arizona Mining Co. was formed, and the Texas Arizona mine was opened at the site of the discovery. The company, with J. R. Hubbard of Tucson as manager, did considerable development work and made small ore shipments from time to time from 1910 to 1917, when work ceased. Various other operators made a few small shipments of ore from the property in 1920–28. In recent years the mine has been held by the Chambers family, who, in 1949, drove an exploratory drift on the lowest level without finding ore. Recorded production for the period 1909–28 was 712 tons of ore averaging about 40 percent lead and 50 ounces of silver per ton. Some oxidized zinc ore was shipped in 1911–13.

The ore at the Texas Arizona mine is mostly in small replacement lenses in limestone. Other deposits of the same kind have been found south of the mine; and some small quartz veins carrying lead and silver occur 3 to 4 miles north of the mine near the present route of Highway 86. These deposits have yielded small shipments of hand-sorted ore, which, like that from the Texas Arizona mine, carried about 1¼ ounces of silver for each 20 pounds (1 percent) of lead.

TUNGSTEN

Tungsten minerals were discovered in 1898, probably by Messrs. Cornelison and Smith, in quartz veins cutting the Texas Canyon quartz monzonite. The discovery was made several miles southwest of Johnson, near the village of Russellville. Prof. W. P. Blake, then Territorial Geologist of Arizona, identified the tungsten minerals as huebnerite and scheelite and published a brief report of the discovery (Blake, 1898, p. 608). Much prospecting followed and many mining claims were located both on the veins and on the placers derived from them. In the year of the discovery, 17 claims were purchased by Stein and Boericke (later Primos Chemical Co.) of Philadelphia, one of the three companies in the United States then making ferrotungsten. High-grade tungsten ore and concentrates were produced before the end of 1898 by this company and also by Asa Walker, A. H. Wien, J. C. Allan, and perhaps other independent operators (Eng. Mining Jour., 1899). Thus the district is among the first worked for tungsten in the United States.

Development and mining of the deposits have been controlled by several factors. The vein deposits are small generally high-grade pockets and shoots widely separated from one another. They are well suited for small-scale mining but not for large-tonnage operations. The widespread distribution of vein deposits favors reconcentration in placers. Although rich placers have been mined, extreme shortage of water limits the scale of operation that is feasible. Most of the ore produced has been secured by single individuals or small groups working with primitive mining and concentrating equipment. The miner commonly works under lease or contract arrangement with the property owner, and is paid according to the pounds of concentrate produced.

Between 1898 and 1915, the placers and veins were worked by a varying number of individuals and groups who took ore from opencuts, short adits, and shallow shafts and concentrated it by handpicking, hand jigs, rockers, long toms, and dry washers. During 1903 the principal tungsten mining in the United States is said to have been in this district and in Colorado (U.S. Geol. Survey, 1904, p. 304).

The rise in the price of tungsten during the war years 1915–18 was an impetus to mining. In 1915 the Primos Chemical Co. built a gravity mill of 5 tons per hour capacity and operated it intermittently for several years. The Banks mill and several other small concentrators were built and operated for short periods. The mills handled both placer and lode ore. Underground mining was carried on at the Bluebird, Dividend, Little Fanny, and several smaller mines. Lessees and small independent operators were very active and produced much of the ore. Gradual exhaustion of deposits readily worked in this way is indicated by a fall in the rate of production per man. It was estimated in 1916 ("Willcox Star," Apr. 28, 1916) that an average of 10 pounds of concentrate was being produced per man per day. This compares with an estimate of 20 pounds in 1908 (Richards, 1908, p. 93) and 50 pounds at the start of placering (Rickard, 1904, p. 264).

Tungsten mining during World War I was not confined to the deposits in the Texas Canyon quartz monzonite. Scheelite had been discovered in 1913 by J. J. Wien in the King vein on the western slope of the Little Dragoon Mountains; these deposits, which were opened by pits and short adits, yielded 5 tons of high-grade scheelite concentrates during the war years, according to Mr. Wien (Wilson, 1941, p. 43). A production of about a hundred pounds of scheelite ore is also reported (Wilson, 1941, p. 44) from the dump of a copper prospect in limestone of Paleozoic age west of Dragoon.

Tungsten production ceased shortly after World War I. The increase in the price of tungsten in the late thirties led to some mining, mostly by lessees. In January 1940 there were, according to Wilson (1941, p. 42–43), some 32 lessees working the Primos Chemical Co. property and other lessees working the Hawk and Hillside groups of claims. The ore was crushed and concentrated by hand jigging. This type of operation continued for several years. Early in 1943, Mr. Elmer Walker, who then held a lease on the Primos Chemical Co. property, obtained a $5,000 loan from the Reconstruction Finance Corporation to recondition the old Primos concentrator for treating dumps from the earlier operations. The venture was unsuccessful, and all tungsten properties were idle in April 1944, when the senior author first visited the area.

In 1949 Messrs. Ray and John Fernstrom of Tucson obtained a lease on the Primos Chemical Co. property and installed concentrating equipment in the old mill; but the mill was never put in operation and the machinery was soon removed. Mr. J. J. Wien obtained a sublease from the Fernstrom interests in the summer of 1949 and mined some ore from an opencut near the Bluebird mine.

In 1952 the Kramer Mining and Milling Co. reopened the Tungsten King mine and built a small gravity concentrator at Pomerene, about 10 miles southwest of the mine. Late in 1953 the property was sold to the Standard Tungsten Corp., 75 West Street, New York City, which built a new concentrator at Pomerene and continued exploration and mining at an increased rate. According to the owners about 6.5 tons of scheelite concentrates were produced between 1952 and October 1954.

In 1953 the Primos Chemical Co. property, consisting of 21 patented claims, was sold to Mr. and Mrs. Elmer Walker, of Dragoon. According to Mr. Walker (oral communication, 1954), lessees, mining largely on spare time, had produced about a ton of concentrates to the end of 1953.

MARBLE

Marble claims were staked by L. R. Ligier in 1909 at the north end of the Dragoon Mountains, where part of the Escabrosa limestone has been recrystallized by dynamic metamorphism into a conspicuous band of snowy white marble. Ownership of the claims was under litigation for many years but, in 1929, the validity of the Ligier claims was established.

Attempts to quarry the white marble as ornamental stone were made as early as 1913 in the first canyon west of Wood Canyon; but these attempts were unsuccessful because the rock is cut by so many fractures and shear planes that large blocks could not be quarried. In recent years, this rock has been used in small amounts as chemical lime by the Apache Powder Co. of Benson. Chemical analyses are said to show 99.2 percent $CaCO_3$, indicating the great purity of the stone.

From 1945 to 1953 various types of colored dimension stone were produced. Operations were concentrated at 3 places, only 1 of which is within the area covered by the geologic map (pl. 1). This is in Wood Canyon where decorative buff to pink, mottled marble was obtained from dynamometamorphosed beds of the Earp formation. Large rectangular blocks were first outlined on the sides by close-spaced pneumatic drill holes; the blocks were then split from the bottom for removal. About 120 holes were made with a 3-inch drifter drill, mounted on a quarry bar, in quarrying the average block which weighed about 10 tons. The blocks were hauled to Dragoon by heavy truck and then shipped by rail to marble-finishing plants.

Up to the present time (1957), the Ligier brothers have carried on all the quarrying by themselves, with the result that the operations have been on a small scale and the product is not very widely known. The colorful character of the stone makes it suitable for special ornamental uses. It has been used for niches, wainscoting, and statuary pedestals in the Nelson Art Gallery in Kansas City, Mo.; in the Sunnyside Mausoleum at Burbank, Calif.; and in various stores, office buildings, and banks in the middle west and along the Pacific coast.

Early in 1950 the Ligier interests installed crushing and screening equipment beside the railroad tracks near Dragoon and started to produce roof granules and terrazzo. These products soon supplanted monumental stone in value.

PRODUCTION

Table 1 summarizes available data on the production of copper, zinc, lead, silver, and gold from the area near Johnson, known for more than 30 years as Johnson Camp. It also summarizes the very small production from other parts of the Dragoon quadrangle, namely from the Texas Arizona mine and other workings in the Gunnison Hills and from the Centurion and other mines in the contact zone west of Dragoon. The area is in the Cochise mining district, which has never been consistently defined. Prior to 1939, the published production figures (U.S. Geol. Survey, 1883–1927, U.S. Bur. Mines 1924–1938) for the district included production from the Golden Rule mine, Middlemarch mine, and several other mines in the Dragoon Mountains, Red Bird Hills, and Winchester Mountains. The later figures (U.S. Bur. Mines, 1939–1959) are restricted to the area of this report. So that the table would have a consistent basis and would represent deposits that are related geologically, the figures for 1907–38 were obtained by adding up the production figures for individual properties as given in the U.S. Bureau of Mines' files; and the dollar values are these totals multiplied by the metal prices given in Mineral Resources and Minerals Yearbook.

TABLE 1.—*Copper, zinc, lead, silver, and gold production, Johnson Camp area, Cochise district, Arizona*

Year	Number of producing mines	Ore (tons)	Copper (pounds)	Zinc (pounds)	Lead (pounds)	Silver (ounces)	Gold (ounces)	Total value
Prior to 1907	----------	[1] 20,000	[1] 2,500,000	----------	----------	[1] 60,000	----------	[1] $450,000
1907	4	7,275	523,934	----------	4,147	8,830	----------	110,835
1908	2	447	68,024	----------	----------	1,120	----------	9,573
1909	3	2,788	209,314	----------		2,192	17.92	28,672
1910	4	3,836	271,003	----------	119,778	13,406	28.86	47,522
1911	3	194	15,235	22,423	89,507	4,562	6.00	9,752
1912	7	3,975	604,178	23,800	121,380	22,809	17.10	120,821
1913	9	4,363	790,633	8,155	27,712	19,264	3.59	135,933
1914	6	20,044	2,136,877	----------	77,956	29,761	5.27	303,812
1915	6	42,420	3,661,603	----------	12,995	37,327	2.88	660,377
1916	7	81,221	6,130,841	----------	27,073	59,816	1.00	1,549,435
1917	8	53,359	4,084,329	----------	13,171	44,493	14.00	1,153,106
1918	6	43,893	3,877,495	----------	----------	31,698	1.00	989,460
1919	4	12,090	1,130,622	----------	----------	8,568	1.00	219,913
1920	3	11,139	1,055,293	----------	48,818	11,383	3.00	210,549
1921	1	17	451	----------	12,684	839	1.00	1,489
1922	1	25	941	----------	----------	7	----------	134
1923	2	28	4,599	----------	3,911	252	----------	1,156
1924	2	599	69,476	----------	----------	495	----------	9,433
1925	4	2,239	215,941	----------	----------	1,845	----------	31,994
1926	3	221	27,591	----------	----------	368	1.00	4,113
1927	3	71	7,079	----------	3,592	164	----------	1,247
1928	5	946	64,643	----------	703	772	.54	9,812
1929	3	453	56,349	----------	----------	592	1.03	10,254
1930	4	1,335	143,201	----------	----------	1,649	.90	19,238
1931	2	128	31,315	----------	----------	789	1.40	3,108
1932–35[2]								
1936	1	10	2,373	----------	----------	12	----------	227
1937	1	39	3,694	----------	----------	22	----------	464
1938[2]								
1939	1	18	3,077	----------	----------	3	----------	322
1940	1	22	3,602	----------	----------	----------	----------	407
1941	1	891	116,000	----------	----------	938	1.00	14,390
1942	3	7,395	413,000	567,000	17,300	3,631	17.00	107,040
1943	1	193	8,700	----------	----------	59	----------	1,173

See footnotes at end of table.

TABLE 1.—*Copper, zinc, lead, silver, and gold production, Johnson Camp area, Cochise district, Arizona*—Continued

Year	Number of producing mines	Ore (tons)	Copper (pounds)	Zinc (pounds)	Lead (pounds)	Silver (ounces)	Gold (ounces)	Total value
1944	2	4, 351	229, 200	95, 500	----------	1, 447	----------	$42, 858
1945	2	33, 183	985, 000	2, 600, 000	3, 500	6, 217	8. 00	436, 977
1946	2	58, 110	1, 974, 500	5, 753, 500	200	12, 062	----------	1, 031, 564
1947	1	66, 583	2, 072, 000	6, 285, 200	8, 000	15, 580	----------	1, 210, 881
1948	1	67, 150	1, 936, 700	5, 749, 300	----------	15, 777	----------	1, 199, 200
1949	2	37, 566	1, 377, 200	3, 519, 900	----------	11, 079	----------	717, 803
1950	2	21, 823	996, 200	2, 050, 400	800	9, 469	12. 00	507, 465
1951	1	64, 654	2, 700, 000	6, 486, 000	----------	23, 475	23. 00	1, 855, 903
1952	1	77, 748	3, 676, 000	8, 532, 000	----------	26, 930	22. 00	2, 330, 812
1953	1	76, 836	3, 698, 000	7, 786, 000	----------	28, 889	12. 00	1, 983, 282
1954	1	76, 880	3, 894, 600	7, 132, 000	----------	30, 857	----------	1, 947, 090
1955	1	75, 128	3, 896, 500	6, 590, 500	----------	34, 046	----------	2, 294, 839
1956	1	76, 668	3, 337, 400	5, 590, 200	----------	31, 147	----------	2, 212, 442
1957	2	44, 716	2, 208, 900	5, 019, 500	----------	22, 926	----------	1, 267, 890
1958	2	1, 410	31, 300	----------	400	193	----------	8, 454
1959	1	28, 979	746, 900	1, 026, 400	----------	7, 777	----------	354, 373
Total	----------	1, 133, 459	61, 991, 813	74, 837, 778	593, 627	645, 537	202. 49	25, 617, 594

[1] Estimated.
[2] No production for Johnson Camp area.

The amount of tungsten produced is not known and cannot be estimated accurately, because most of it was mined from surface pockets and placers of unknown grade by many constantly changing small operators. Figures reported by various operators, statements in contemporary newspapers and mining journals, and observations made in the course of geologic mapping suggest the total production may have been about 75,000 units of WO_3. A unit of WO_3 is 20 pounds of tungsten trioxide. Tungsten concentrates are generally sold on the basis of units of contained tungsten trioxide.

Marble production for 1953–59 is given in table 2. The amount of marble produced prior to 1953 is not known.

TABLE 2.—*Marble production from Ligier quarries near Dragoon, Ariz., 1953–59*

Year	Dimension stone		Terrazzo		Other uses			Total crushed	
	(Short tons)	(Value)	(Short tons)	(Value)	(Short tons)	(Value)		(Short tons)	(Value)
1953	30	$1, 800	300	$6, 000	600	$12, 000	Roof chips	900	$18, 000
1954	--------	--------	115	2, 530	500	11, 002	-----do	615	13, 532
1955	--------	--------	41	820	--------	--------	--------	41	820
1956	--------	--------	236	4, 556	640	10, 205	Roofing granules	--------	--------
					234	1, 844	Plaster	1, 110	16, 605
1957	--------	--------	700	15, 400	1, 000	14, 100	Roofing granules	1, 700	29, 500
1958	--------	--------	900	16, 300	600	10, 800	-----do	1, 500	27, 100
1959	--------	--------	1, 376	29, 067	1, 000	15, 000	-----do	2, 376	44, 067
Total	30	1, 800	3, 668	74, 673	4, 574	74, 951	--------	8, 242	149, 624

MINERALOGY

This section gives notes on the mode of occurrence and characteristics of minerals found in the ores and associated rocks. The order of presentation is that of Dana's "System of Mineralogy."

NATIVE ELEMENTS

Native copper (Cu).—Traces of native copper are found in the oxidized ores at the Mammoth, Republic, Copper Chief, and other mines in the Johnson district. The mineral is clearly of supergene origin. In the ores mined in recent years, it is confined to local oxidized zones along faults that provided channelways for deep circulation of ground water.

SULFIDES

Tetradymite (Bi_2Te_2S).—Tetradymite, in blades of microscopic size, is commonly intergrown with galena in the tungsten veins of the area. We are indebted to Charles Milton of the Geological Survey for identification of the mineral. Galena intergrown with tetradymite can be recognized at many places by satiny luster and octahedral parting. Galena with octahedral parting and intergrown tetradymite has been described by Wahlstrom (1937) from hypothermal veins in Boulder County, Colo. It is there associated with pyrite, chalcopyrite, sphalerite, and molybdenite, and it contains plates of tetradymite about 0.005 mm thick arranged parallel to the octahedron (111). He believes the tetradymite is due to exsolution. The galena from the tungsten veins of the Dragoon quadrangle has thin oriented tetradymite plates like the Colorado mineral and, in addition, scattered blades of slightly larger size without consistent orientation. We have examined six polished sections of galena from the veins. Five of these specimens, including a specimen from the contact vein at the Tungsten King mine, showed intergrown tetradymite. Tetradymite was not detected in galena from a vein in Paleozoic sedimentary rocks. The occurrence of galena with unmixed tetradymite in the tungsten veins is not surprising as other bismuth minerals are commonly associated with tungsten (Li and Wang, 1955, p. 18–34). G. H. Espenshade (oral communication, 1951) has observed galena with octahedral parting and inclusions of some bismuth mineral, possibly tetradymite, in the quartz-huebnerite veins near Henderson, N.C.

Digenite [$Cu_{2-x}S$; x=0.12 to 0.45(?)].—Digenite has been identified in ore specimens from the Black Prince (Copper Bell) adit and several nearby prospects. The digenite is intergrown with chalcopyrite that forms a lattice of minute blades in the digenite. This intergrowth has replaced bornite along cracks and grain boundaries. The chalcopyrite blades evidently formed along the octahedral cleavage planes of the bornite as the replacement took place. The ratio of digenite to chalcopyrite is approximately 2:1, and thus the composition of the intergrowth as a whole is nearly the same as the bornite. The bornite molecule is equivalent to 2 chalcocite molecules and 1 chalcopyrite molecule as shown by the following equation:

$$Cu_5FeS_4 \text{ (bornite)} = 2\ Cu_2S \text{ (chalcocite)} + CuFeS_2 \text{ (chalcopyrite)}.$$

The fact that digenite formed rather than chalcocite suggests that either a little copper was removed or a little sulfur was added in the alteration process. Supergene covellite of later formation replaces the digenite and to some extent the chalcopyrite and bornite as well.

Chalcocite (Cu_2S).—Small amounts of chalcocite, evidently supergene, have been observed in oxidized ore at Johnson, at the Centurion mine and in several quartz-tungsten base metal veins in the Texas Canyon quartz monzonite. It is not an important ore mineral at present although it may have been important when shallower ore bodies were being mined. It is generally less abundant than covellite.

Stromeyerite(?) [$(Ag, Cu)_2 S$] *and sternbergite(?)* ($AgFe_2S_3$).—Polished surfaces of ore from the Black Prince (Copper Bell) adit showed microscopic grains of two unidentified metallic minerals—one light gray and strongly anisotropic, the other brownish-brass-colored and strongly anisotropic. Charles Milton (written communication, 1947) stated that they are possibly stromeyerite and sternbergite respectively. Although the identifications are very uncertain, it is known that silver is most abundant in this part of the district. Recorded shipments of ore from the Peabody and Black Prince mines averaged 4 or 5 ounces of silver per ton, whereas those from the Republic, Copper Chief, and Mammoth mines have averaged considerably less than 1 ounce.

Bornite (Cu_5FeS_4).—Bornite is a common mineral in the pyrometasomatic deposits, particularly in and near quartz veins and pockets. It is far less abundant than chalcopyrite at the Republic and Mammoth mines but is an important ore mineral in the Black Prince-Peabody area where it locally exceeds chalcopyrite in abundance.

Galena (PbS).—Galena, associated with sphalerite, chalcopyrite, and pyrite, is a late-formed mineral in the quartz-tungsten veins. At several localities the galena fills pockets lined by euhedral quartz crystals which were corroded and etched by the late solutions. Much of the galena in the tungsten veins is intergrown with tetradymite. A little microscopic galena was identified by Charles Milton (written communication, 1947) in silicate ore from the Black Prince (Copper Bell) adit. Remnants of galena, embedded in anglesite, cerussite, and other oxidized minerals, are abundant in the ore from the Texas Arizona mine and other lead deposits in the Gunnison Hills.

Sphalerite (ZnS).—Sphalerite is common in the ores of the area. Minor amounts of a pale greenish-brown variety are common as a late mineral in the quartz-tungsten veins in the Texas Canyon quartz monzonite. A grayish-brown to almost black variety is the primary zinc mineral in the pyrometasomatic deposits. Traces of a green variety were observed in coarse-grained wollastonite-vesuvianite-diopside rock about 100 feet stratigraphically below the Main Manto ore body on the northwest crosscut on the 700 level of the Republic mine. The sphalerite in the tungsten veins and pyrometasomatic deposits is characteristically flecked with microscopic exsolved(?) blebs of chalcopyrite, but these blebs are missing in a few specimens from the Peabody mine.

Chalcopyrite ($CuFeS_2$).—Chalcopyrite is the main ore mineral of copper in the pyrometasomatic deposits. Most of it was formed at the same time as sphalerite but some is younger as indicated by a few chalcopyrite seams cutting the sphalerite. A little chalcopyrite is also associated with sphalerite, galena, and bornite in the quartz veins of the area.

Pyrrhotite ($Fe_{1-x}S$; x=0 to 0.2).—A little strongly magnetic pyrrhotite was noted in partly silicated limestone in one of the drill cores near the Mammoth mine. Other metallic minerals are absent from this part of the core.

Covellite (CuS).—Covellite, clearly of supergene origin, is common in the upper parts of the cupiferous veins and pyrrometasomatic deposits, occurring as minute blades replacing the other sulfide minerals. Covellite is absent from the deep ores.

Pyrite (FeS_2).—Pyrite is a widespread mineral but is rarely very abundant. A little occurs in quartz veins and in the altered rock adjacent to them. It makes up a trace to perhaps 5 or 10 percent by weight of the pyrometasomatic ores and is disseminated in some of the associated metamorphic rocks that are free of ore minerals.

Marcasite (FeS_2). Marcasite occurs as narrow seams and euhedral crystals coating cavities along faults in the mines near Johnson. The mineral was cretainly formed late, probably by downward-percolating acidic waters of meteoric origin.

Molybdenite (MoS_2).—Molybdenite is widely but sporadically distributed in the metamorphosed carbonate rocks near Johnson. Its distribution bears little relation to that of copper and zinc minerals. The richest concentrations are found in sheared silicate rock some distance from copper-zinc ore bodies. In general the amount increases southeast of the Republic mine, as though it favored proximity to the Texas Canyon stock. Molybdenite is extremely scarce, however, in quartz-tungsten veins in the intrusive rock. In examining several hundred of these veins, only one minute crystal doubtfully identified as molybdenite was found. At two localities a little powellite as pseudomorphs after molybdenite was detected.

SULFOSALTS

Tetrahedrite ($3Cu_2S \cdot Sb_2S_3$).—Tetrahedrite (identification checked by Charles Milton) is locally abundant in small quartz veins that cut ore in the Republic mine; such veins that are rich in tetrahedrite were found in the West Manto raise and in the North winze below the 900 level. The tetrahedrite is generally associated with sphalerite, chalcopyrite, bornite, galena, and fluorite in the veins. Tetrahedrite has not been observed in the pyrometasomatic ores.

HALIDES

Cerargyrite(?) (AgCl).—Horn silver, or cerargyrite, has been reported from the Texas Arizona mine (John Walker, oral communication, 1950) but none was found during our survey.

Fluorite [CaF_2].—Colorless, pale-blue, pink or deep-purple fluorite is a characteristic mineral of the tungsten veins in and near the Texas Canyon quartz monzonite and of the altered rock immediately adjacent to these veins. There is no apparent relation between the amount of fluorite and the amount of tungsten in the veins; and fluorite is found in many barren veins in the quartz monzonite and associated aplite. At Johnson, fluorite is common in small quartz-orthoclase veins associated with copper and zinc sulfides. It is lacking from most of the pyrometasomatic ore but has been observed in these ores at a few places, notably at the Peabody mine. It is associated with specularite in veins cutting the Johnny Lyon granodiorite near the American shaft. Fluorite from the Little Fanny tungsten mine fluoresces blue and phosphoresces green. Neither fluorescence nor phosphorescence was noted in specimens from other localities.

OXIDES

Cuprite (Cu_2O).—Deep-red splendent crystals of cuprite associated with malachite were found lining pockets in quartz veins in the Texas Canyon quartz monzonite. Cuprite was not positively identified at Johnson but is probably a constituent of fine-grained nearly black oxidized copper ores.

Tenorite(?) (CuO).—Tenorite is a probable constituent of black copper pitch ores found in the oxidized zone at Johnson. These ores, the mineralogy of which was not worked out, are mostly dull and earthy but are in part lustrous and fracture conchoidally.

Hematite (Fe_2O_3).—Small amounts of specular hematite occur in quartz veins that cut the Pinal schist and are probably of earlier Precambrian age. It occurs also in contact metamorphosed quartzite adjacent to diabase sills of late Precambrian age. Earthy hematite was concentrated by Precambrian weathering of the diabase. Specularite, probably of Late Cretaceous or Tertiary age, is abundant at the American shaft replacing the Johnny Lyon granodiorite. Hematite is very scarce and confined to earthy supergene varieties in most parts of the metamorphic zone surrounding the Texas Canyon quartz monzonite, though specularite is disseminated locally in lime-silicate rock between the Republic and OK mines, and martite was noted in narrow veins west of Dragoon.

Ilmenite ($FeTiO_3$).—Float specimens of vein quartz containing black plates of ilmenite as much as 1 mm thick and 25 mm in diameter were found near the Seven Dash Ranch. The specimens probably came from a Precambrian vein in the Pinal schist.

Manganese oxides.—The quartz-huebnerite veins contain pyrolusite both as black acicular crystals in vugs and as black masses a few inches in diameter. The identification of both varieties has been checked by Charles Milton. The pyrolusite is probably supergene.

No tungsten was detected in the massive pyrolusite by crude chemical tests made by Charles Milton. The tests were made because of the presence of tungsten in pyrolusite at Golconda, Nev., and elsewhere and because the manganese in this pyrolusite may have been derived in part from the tungsten mineral huebnerite. Small quantities of powdery manganese oxide occur near Johnson as a weathering product of manganiferous vein carbonates. In the Steele Hills, brownish-black manganese oxide is concentrated in the Threelinks conglomerate immediately beneath the Galiuro volcanics. The manganese mineral has replaced pebbles and matrix material in a zone 1 to 6 inches thick. It was evidently formed by weathering processes before the overlying volcanic rock was deposited.

Limonite (mixture of hydrous iron oxides).—Limonite is conspicuous in the outcrops of sulfide-bearing rocks and is found as deep as oxidation has gone.

Magnetite ($FeFe_2O_4$).—Magnetite is an accessory mineral of the igneous rocks. It is rare in the contact metamorphic rocks near Johnson although found in small quantities in ore specimens from the Republic mine. In the narrow martite veins west of Dragoon enough magnetite remains to make the material magnetic. The other minerals in these veins are epidote, garnet, anthophyllite, a peculiar high-birefringent serpentine(?), and a little chalcopyrite, chalcocite, chrysocolla, supergene calcite, and chalcedony.

CARBONATES

Calcite ($CaCO_3$).—Calcite is the chief constituent of sedimentary limestone, and some generally remains in the same beds after metamorphism. At many places metamorphism has produced calcite from dolomite. A slightly manganiferous calcite occurs as very late veinlets in the mines near Johnson. A variety containing appreciable quantities of manganese and iron occurs as a hypogene mineral in some of the quartz-tungsten veins. Its color ranges from pale buff to dark chestnut brown; differences in the color are caused by the relative abundance of microscopic brown inclusions. The index of refraction (ω) ranges from about 1.698 in the palest parts to about 1.66 (pure $CaCO_3$) in the darkest. The high-index pale part is calcite, not dolomite, as shown by X-ray analysis in the Geological Survey laboratory. Evidently the mineral as first formed contained both manganese and iron in solid solution but was unstable under near-surface oxidizing conditions and broke down into pure calcite and the brown inclusions, presumably manganese and iron oxides. Some of the manganese released may have formed the supergene pyrolusite found in the veins. Supergene calcite is found in caliche crusts, as seams along cracks, and as euhedral crystals lining vugs and cavities. Some of the seams in the contact metamorphic rocks and quartz-tungsten veins fluoresce bright red. K. J. Murata (oral communication, 1949) has shown that red fluorescence in calcite is caused by the presence of manganese and lead.

Cerussite ($PbCO_3$).—Cerussite, in formless masses or rarely in minute bladed crystals, is an important ore mineral at the Texas Arizona mine and in the lead veins at the north end of the Gunnison Hills. Small amounts were noted also in a lead vein west of Dragoon. Associated minerals are anglesite, galena, limonite, and malachite.

Dolomite ($CaMg(CO_3)_2$).—Beds of dolomite are common in the Paleozoic section and many of these beds are represented by dolomite marble in zones of metamorphism. Postore veinlets of gray to flesh-colored dolomite, in places associated with a little quartz, chalcopyrite, and sphalerite, occur at a few places along faults in the mines at Johnson. A little dolomite, apparently of hydrothermal origin, is associated with quartz and galena at the Texas Arizona mine. The only other evidence of dolomite that might be connected with ore formation is the partial dolomitization of limestone near a few faults in the Gunnison Hills.

Hydrozincite ($Zn_5(OH)_6(CO_3)_2$).—White chalky masses of hydrozincite as much as 6 inches by 24 inches in size are found along fissures in the Texas Arizona mine. The masses are aggregates of microscopic bladed crystals, which fluoresce bright blue, like scheelite.

Aurichalcite ($2(Zn,Cu)CO_3 \cdot 3(Zn,Cu)(OH)_2$).—Pale bluish-green to delicate sky-blue aurichalcite is fairly common in the oxidized ores at Johnson. In specimens from the Peabody dump, it occurs as botryoidal masses of radiating blades and as tufts and druses of discrete bladed crystals, a few millimeters long, in cracks and vugs lined by an earlier crust of hemimorphite. A later generation of hemimorphite coats the aurichalcite at some places.

Rosasite(?) ($(Cu,Zn)_2(OH)_2(CO_3)$).—Traces of a pale-green carbonate mineral, doubtfully identified as rosasite, were found in oxidized ore fragments on the Texas Arizona dump. The mineral has negative elongation, $\alpha = 1.68$ and β and $\gamma > 1.78$.

Malachite ($CuCO_3 \cdot Cu(OH)_2$).—Malachite is generally prominent in the oxidized zone of the cupriferous deposits and occurs as stains, veinlets, and druses of minute crystals. Traces of the mineral were also observed far from any known occurrences of copper sulfides—as on Johnson and Lime Peaks, in the Gunnison Hills, and at the north end of the main Dragoon range.

Azurite ($2CuCO_3 \cdot Cu(OH)_2$).—Traces of azurite, little more than stains, are associated with malachite at places.

SULFATES

Barite ($BaSO_4$).—Barite has been identified at only two places in the area: In a quartz vein 1,500 feet west of the Mammoth mine, associated with galena, pyrite, and chalcopyrite; and near the American shaft as white cleavable masses embedded in quartz and specularitic vein matter.

Anglesite ($PbSO_4$).—Fine-grained gray anglesite associated with cerussite is common in the Texas Arizona mine and nearly all the lead veins of the region as an oxidation product of galena.

Gypsum ($CaSO_4 \cdot 2H_2O$).—Small amounts of gypsum occur along some faults in the mines at Johnson and at other places where supergene sulfate waters reacted with limestone.

Melanterite(?) group ($R''SO_4 \cdot 7H_2O$).—Unidentified hydrated sulfates of iron, copper, and possibly zinc occur as efflorescences in mine workings at Johnson. Presumably they belong in the melanterite group.

Linarite(?) ($PbCu(SO_4)(OH)_2$).—Traces of a deep azure blue mineral, with optical properties suggesting linarite, occur in oxidized ore at the Texas Arizona mine.

Jarosite ($KFe_3(SO_4)_2(OH)_6$).—Jarosite and related minerals which contain the ore metals are probable constituents of yellow pulverulent material occurring in small quantities in the oxidized zone at the Texas Arizona mine and at Johnson. Minute hexagonal tablets of virtually pure jarosite coat quartz in the oxidized part of the Tungsten King vein and also are embedded in silica breccia in the Gunnison Hills, where they are associated with scarce molds of pyrite cubes and a prismatic mineral probably belonging in the apatite group.

PHOSPHATES AND VANADATES

Mottramite [$(Cu,Zn)Pb(VO_4)(OH)$].—An olive-green mineral, identified by Charles Milton as a lead-copper vanadate nearly free from zinc, and therefore mottramite occurs as incrustations on quartz in the tungsten veins and in some barren veins in the Texas Canyon quartz monzonite.

Apatite ($Ca_5(PO_4)_3(F,Cl,OH)$).—The igneous and metamorphic rocks of the area generally contain accessory aptite in microscopic crystals. Colorless apatite, which fluoresces peach to orange-yellow, occurs in and near quartz-tungsten veins in the Texas Canyon quartz monzonite. The most common mode of occurrence is as grains a few millimeters in diameter in the intensely altered quartz monzonite adjacent to the veins. Stubby crystals as much as 12 mm in length were found in the quartz at a few places. Ulrich and Maly (1940) report that apatite from most pegmatites and cassiterite veins shows a strong yellowish- or pinkish-brown fluorescence; other apatites show a deeper one of dark violet. This suggests that cassiterite veins and the quartz-tungsten veins were formed under similar conditions.

TUNGSTATES AND MOLYBDATES

Huebnerite ($MnWO_4$).—Deep reddish-brown huebnerite is the principal ore mineral in tungsten veins in the Texas Canyon quartz monzonite and adjacent Pinal schist. It occurs as platy cleavable crystals 0.3 to 10 cm long and is commonly aggregated in bunches and lenses in the quartz. Hess (1917, pl. 11B; Hess and Schaller, 1914, pl. 13A, p. 24–25) published pictures of the huebnerite and quoted the following chemical analysis and recalculated analysis:

	Original analysis	*Recalculated analysis*
WO_3	75. 36	76. 5
FeO	2. 66	2. 8
MnO	19. 50	20. 7
CaO	--------	---------
SiO_2	1. 70	---------
Undetermined	0. 78	---------
$FeWO_4$	--------	11. 6
$MnWO_4$	--------	88. 4
Excess FeO	--------	0. 1
$CaWO_4$	--------	4. 1

Scheelite ($CaWO_4$).—Scheelite is more widely distributed in the area than huebnerite but has been of less economic value. Veins in the northern part of the Texas Canyon stock and adjacent schist contain 1 part scheelite to about 10 parts of huebnerite; the scheelite occurs as a fine-grained replacement of huebnerite and as dipyramidal crystals as much as 2 cm in diameter embedded in massive quartz, encrusting quartz crystals in vugs, and rarely included in the quartz crystals of the vugs. Quartz veins in quartz monzonite and limestone southwest of the Centurion mine contain local scheelite-rich streaks and lenses that lack huebnerite. The Tungsten King vein also carries scheelite but no huebnerite.

The vein scheelite is generally pale brown but at some places practically colorless. It fluoresces blue-white which, according to the scheelite fluorescence comparator,[11] indicates 0.05 to 0.14 percent molybdenum. Small amounts of colorless scheelite are common in the tactite near Johnson and at a few places in tactite and marble near the quartz monzonite southwest of the Centurion mine. This scheelite ranges in fluorescence from blue white to yellow, often within short distances. The yellowest fluorescence, which indicates between 1 and 2.4 percent molybdenum in the mineral according

[11] Devised by R. S. Cannon, Jr., and K. J. Murata of the Geological Survey.

to the comparator, was found between the Republic mine and the quartz monzonite contact near the Keystone mine, an area also containing a relatively high concentration of molybdenite. There is a rough correlation between the amount of scheelite and amount of copper and zinc minerals in the pyrometasomatic deposits.

Powellite ($CaMoO_4$).—Powellite, evidently of supergene origin, occurs as pseudomorphs after molybdenite near Johnson and at two known localities in quartz-tungsten veins. The powellite, which fluoresces yellow, may be distinguished from high-molybdenum scheelite by distinctly yellower fluorescence, pseudomorphic habit, and powdery character, which causes it to form a fluorescent smear on a finger rubbed lightly across it.

Wulfenite ($PbMoO_4$).—A little wulfenite was found in the oxidized part of lead-bearing quartz veins in the Texas Canyon quartz monzonite and in similar veins near the Mammoth and Tungsten King mines.

Stolzite ($PbWO_4$).—Stolzite from the "Primos mine" (probably the Bluebird mine) was described by Palache (1941, p. 430). None was found during our work.

Cuprotungstite ($Cu_2(WO_4)(OH)_2$).—Green scheelite from a quartz-huebnerite vein in quartz monzonite half a mile southwest of Johnson is not homogeneous under the microscope but consists of scheelite and included green material which has a spherulitic habit and higher indices and birefringence than the scheelite. The green material, which is almost certainly cuprotungstite, is concentrated as very thin seams and spherules 0.01 to 0.03 mm in diameter which are along cracks in the scheelite.

SILICATES

Quartz (SiO_2).—Quartz is a very abundant and widespread mineral formed at different times and by different processes. It is a primary mineral in many of the igneous, sedimentary, and metamorphic rocks. It is the main constitutent of many hydrothermal veins, formed mostly by filling open fissures but partly by replacement. The filling of some veins was accomplished in several stages, and intersection of one vein by another indicates several stages of vein formation. Quartz of replacement origin is abundant in the altered zones of the quartz monzonite. Some late introduced quartz is intimately associated with the ore minerals of the pyrometasomatic deposits. Quartz was also formed by supergene processes in the zone of oxidation as proved by euhedral glassy quartz coating malachite.

Chalcedony (SiO_2).—A little chalcedony as narrow veinlets and thin colloform crusts is common in the zone of oxidation. Like the supergene quartz it has been observed coating oxidized copper and iron minerals. Much of the chalcedony fluoresces pale bluish green but some is not fluorescent.

Opal ($SiO_2 \cdot nH_2O$).—A little opal has been observed in many parts of the area as thin colloform incrustations in the zone of oxidation where it was commonly the last mineral formed. Most of it is clear and colorless but some is tinted and opalescent. Nearly all specimens fluoresce bright yellowish green, but one specimen from the Centurion mine fluoresces pale blue. The index of refraction ranges from 1.44 to 1.46.

Orthoclase and microcline ($KAlSi_3O_8$).—The potassium feldspars orthoclase and microcline are abundant as primary constitutents of the felsic igneous rocks and as detrital grains in sedimentary rocks of Precambrian age. They also make up 10 to 40 percent of impure limestone and dolomite of the Abrigo formation; they occur partly as rounded detrital grains but mostly as bladed crystals that are probably authigenic. Orthoclase is very common in the metamorphic rocks near Johnson and generally makes up 15 to 50 percent of white tactite derived from the Abrigo formation and of porcellanite derived from calcareous or dolomitic shale. It is less abundant in garnetite. The feldspar is interstitial to the other silicates and is generally not recognizable in hand specimens. Potassium feldspar is also a conspicuous constituent of quartz veins near Johnson and near the Tungsten King mine. Some of these veins also contain fluorite, calcite, base-metal sulfides, and tungsten minerals.

Plagioclase (albite, $NaAlSi_3O_8$, to anorthite, $CaAl_2Si_2O_8$).—Except for occurrences in igneous rocks, plagioclase is far less abundant than potassium feldspar. It is rare in the unmetamorphosed facies of the Paleozoic section and has been detected in only a few specimens of the metamorphosed facies of these rocks. Andesine (near An_{45}), evidently of metamorphic origin, makes up about 25 percent of a specimen from the base of unit 7 of the Martin formation near the Mammoth mine. Oligoclase is a constituent of metalized seams cutting lamprophyre at the Peabody mine; and albite (about An_5) occurs in metamorphosed and metalized calcareous shale at the Mammoth mine.

Diopside [$CaMg(SiO_3)_2$].—Colorless to very pale green or brown diopside is very abundant and widely distributed in the metamorphosed carbonate rocks near Johnson. It is a major constituent of white tactite and porcellanite that lack garnet and also of the garnetite. The optical properties of the diopside indicate a variation in composition from the pure mineral in metamorphosed siliceous dolomite to diopside$_{85}$ hedenbergite$_{15}$ in metamorphosed calcareous and dolomitic shale, and diopside$_{78}$ hedenbergite$_{22}$ in an ore specimen from the Republic mine.

Wollastonite ($CaSiO_3$).—White acicular wollastonite, commonly associated with idocrase, occurs locally in the garnetite near the Texas Canyon stock. Greenish-gray wollastonite needles, in part replaced by sphalerite, are the chief gangue of high-grade sphalerite ore specimens found on the dump of the Peabody mine. Southwest of the Peabody mine, selvages of acicular wollastonite, which weather pale brown, occur between garnet rock and the pure calcite marble that was replaced.

Anthophyllite [$Mg_7Si_8O_{22}(OH)_2$].—Anthophyllite was found at only one locality, in a narrow martite vein cutting the Horquilla limestone, 2,000 feet northwest of the Empire No. 2 shaft, west of Dragoon. The mineral is gray, asbestiform, and in part in cross-fiber veinlets. The fibers are readily separable but weak and easily broken. Under the microscope they have parallel extinction and positive elongation with α near 1.63 and γ slightly above 1.65. Pleochroism is distinct with X brownish green, Z green, and X>Z. These properties fit anthophyllite with about 25 mole percent $Fe_7Si_8O_{22}(OH)_2$ in solid solution.

Tremolite [$Ca_2Mg_5(OH)_2(Si_4O_{11})_2$] *Actinolite* ($Ca_2(Mg,Fe)_5(OH)_2(Si_4O_{11})_2$) group.—Nearly pure colorless tremolite ($\gamma<1.63$) is the distinctive silicate in an outer zone of metamorphism of the siliceous dolomite near Johnson, and it is preserved in the highest grade metamorphic facies of some of the beds. The metamorphic tremolite formed from argillaceous beds probably contains a few percent of the actinolite molecule. Small amounts of actinolite (very weakly pleochroic with γ1.64 to 1.653), which is commonly associated with chlorite, calcite, and base-metal sulfides, have replaced diopside and other metamorphic silicates. The variety with the highest index of refraction and presumably the greatest iron content was found in ore.

Hornblende (basic silicate of Ca, Mg, Fe, Al, and alkalies).—Hornblende is a primary constitutent of lamprophyre dikes at the Peabody mine and elsewhere. It was not detected in metamorphic rocks near Johnson but was found at two localities farther south—in metamorphosed shale at the Standard prospect and associated with alkalic feldspars, lime silicates, and oxidized copper minerals on the dump of the Empire No. 2 shaft, west of Dragoon. At both localities the mineral is in deep-brown to black crystals that are strongly pleochroic in shades of brown and green. At the Empire No. 2 locality it is partly altered to a soft bronzy-brown aggregate of biotite(?) and iron oxides.

Beryl ($Be_3Al_2(SiO_3)_6$).—Small amounts of sky-blue to colorless beryl occur locally in the King and related veins on the western slope of the Little Dragoon Mountains. Specific localities are in and near the Tungsten King mine, in the Black vein half a mile to the southwest, and in a small vein in Sheep Basin, 2 miles to the south (SW¼NE¼ sec. 18, T. 16 S., R. 22 E.). The beryl is in slender crystals and columnar aggregates, as much as 2 cm long, embedded in quartz or in vugs and also in small (0.5 to 5 mm) irregular masses in hydrobiotite schist (fig. 30) that is injected by vein matter. The beryl-bearing parts of the veins commonly contain enough muscovite and alkalic feldspar to resemble pegmatite, and in places they also contain base-metal sulfides, fluorescent apatite, and scheelite. The indices of refraction of the beryl are variable (ω from about 1.585 to about 1.598) and higher than those recorded for the pure mineral. This is said to be characteristic of the beryl in tungsten veins (J. W. Adams, oral communication, 1953). Beryl has been reported (Galbraith, 1947, p. 83) at the Boericke (Primos Chemical Co.) tungsten property but we did not find it there or at other localities in the Texas Canyon stock.

Garnet group ($R''_3R'''_2(SiO_4)_3$).—Garnet is the most abundant and characteristic silicate in the metamorphosed limestone surrounding the Texas Canyon stock, but it was not formed in the dolomite—at least in the vicinity of Johnson. The garnet is in dodecahedral crystals or close-packed irregular granules generally 1 mm or less in diameter. It is anisotropic in thin section and in places extinguishes in triangular or rhombic segments or in concentric zones. Much of it is pale yellowish or greenish brown. At some places it grades to reddish brown next to residual pockets of quartz or calcite. The index of refraction increases with depth of color from 1.74 in the pale varieties to more than 1.78 in the local reddish-brown phases. Because of these properties and the mode of occurrence, the garnet is regarded as the calcium-aluminum variety grossularite, with some iron and perhaps other elements in the crystal structure. Baker (1953, p. 1274) found a relatively high proportion of manganese in the reddish-brown rims.

Forsterite (Mg_2SiO_4).—Glassy colorless forsterite occurs in the metamorphosed facies of low-silica dolomite, such as the lower serpentine marker at Johnson (fig. 10). The optical properties of the forsterite—biaxial positive, 2V near 90°, α near 1.637, γ near 1.672—indicate it is practically pure Mg_2SiO_4. At most places the mineral has been completely altered to serpentine.

Willemite (Zn_2SiO_4).—Minute glassy prisms of willemite, which fluoresce straw yellow, occur in oxidized lead ore at the Texas Arizona mine and also coat cracks in the limestone near the lead ore bodies. Willemite was found also as a drusy coating of hexagonal prisms on sphalerite and galena in a quartz-tungsten vein 1,000 feet southeast of the Little Fanny mine. The mineral was evidently formed by supergene processes as in many other arid areas (Pough, 1941, p. 98).

Idocrase [$Ca_{10}(Mg,Fe)_2Al_4(SiO_4)_5(Si_2O_7)_2(OH)_4$].—Pale-brown idocrase, commonly associated with wollastonite, occurs locally in the garnetite near the Texas Canyon stock. It is abundant in the gangue of rich bornite-chalcopyrite ore from the Black Prince (Copper Bell) adit. At the Peabody mine it was found as square vertically striated prisms as much as 2 mm long lining a vug that was partly filled with sphalerite and chalcopyrite.

Andalusite (Al_2SiO_5).—Square prismatic porphyroblasts of andalusite as much as 2 inches long occur in schist derived from the Morita and Cintura formations near the Texas Canyon stock. Many of the metacrysts have the symmetrically distributed dark inclusions of chiastolite. Andalusite was not found in metamorphosed shale of Paleozoic age.

Sillimanite (Al_2SiO_5).—Acicular porphyroblasts of sillimanite as much as 1 cm long were found in hornfelsed shale of the Morita and Cintura formations less than 200 feet from their contact with the Texas Canyon quartz monzonite. The locality is in a roof pendant 2 miles southeast of Adams Peak.

Zoisite ($Ca_2Al_3(SiO_4)(Si_2O_7)(OOH)$).—Zoisite is very rare in the lime-silicate rocks but has been identified microscopically in some specimens, including an ore specimen from the 1100 N stope of the Republic mine. Traces of a pink variety, presumably the manganiferous variety thulite, occur locally in vugs and as a coating on joint surfaces.

Epidote group [$Ca_2(Al,Fe)_3(SiO_4)(Si_2O_7)(OOH)$].—Common epidote, the ferriferous pistachio-green optically negative variety, is abundant in the metamorphosed limestone and calcareous shale near the Texas Canyon stock. In a prospect pit 3,300 feet southwest of the Centurion mine and less than 175 feet from the quartz monzonite contact, green epidote rock derived from the Horquilla limestone contains lenses an inch or two in diameter made up of scheelite, calcite, and acicular epidote of an unusual pale-brown color. The brown epidote is optically negative, has a large optic angle, and a distinct inclined dispersion, α near 1.73, β about 1.743, and γ about 1.754. The low-iron optically positive epidote, clinozoisite, was detected in the metamorphic aureole only in metamorphosed and metalized lamprophyre from the Peabody mine and as the main constituent of a 6-inch pink bed in the Morita and Cintura formations near the quartz monzonite west of Dragoon.

Chondrodite [$Mg_5(SiO_4)_2(OH,F)_2$].—Chondrodite was found in the excavation for the settling tank at the concentrator of the Coronado Copper and Zinc Co. at Johnson. At this locality, white tactite of the Martin formation contains irregular replacement lenses an inch or two across of bright-pink material mixed with and surrounded by calcite and fine-grained muscovite. The pink material is too hard to scratch with a knife blade and is an aggregate of several minerals. One has the optical properties of chondrodite. Another is an unidentified mineral with low birefringence and indices of refraction in the 1.67–1.68 range.

Hemimorphite [$Zn_4Si_2O_7(OH)_2 \cdot H_2O$].—Hemimorphite in small colorless crystals is the most abundant oxidized zinc mineral in the Texas Arizona mine. Small chunks of high-grade oxidized zinc ore, largely hemimorphite, were found on the dump of the Peabody mine.

Tourmaline (complex borosilicate of Al and other bases).—Black iron tourmaline is a common mineral in the contact zone of the Johnny Lyon granodiorite and in places near the diabase sills of late Precambrian age. But no tourmaline of any kind was found within the Texas Canyon stock, or in the metamorphic aureole and veins associated with it.

Muscovite [$KAl_2AlSi_3O_{10}(OH)_2$].—Muscovite is widely distributed in the schist, gneiss, and felsic igneous intrusive rocks. It is also common in the King vein and in tungsten veins in the Texas Canyon quartz monzonite. In the latter group of veins, the muscovite is commonly concentrated at the sides as a selvage of pale-greenish plates 1 cm or less in diameter standing normal to the vein walls. Alteration muscovite (sericite) is abundant in the greisenlike altered quartz monzonite adjacent to the veins. The alteration muscovite has the same optical properties as that in the veins and in aplite and pegmatite dikes. Tests in immersion oils indicate that β ranges from 1.59 to 1.605 (average about 1.60) and (−) 2V ranges from 30° to 43° (average about 38°) in each mode of occurrence. Near Johnson muscovite is associated with calcite and chondrodite in small replacement lenses in white tactite near the Coronado mill. A little very fine grained sericite(?) occurs in other metamorphic rocks at Johnson, particularly in hornfels derived from shale. In this fine-grained form, the mode of occurrence must be relied on to distinguish sericite from talc.

Biotite [$K(Fe,Mg)_3AlSi_3O_{10}(OH)_2$].—Biotite is a minor constituent of the Pinal schist and is a primary mineral in most of the felsic igneous rocks. In the metamorphic rocks surrounding the Texas Canyon stock, biotite was formed in considerable quantities from shale of the Abrigo formation. Darkening of these beds, due to the formation of biotite in them, is conspicuous beyond the outer boundary of lime-silicate minerals. In several specimens from the Mammoth mine, radiating aggregates of deep-brown biotite, partly altered to chlorite, are intimately associated with actinolite, chalcopyrite, sphalerite, and pyrite. This biotite and the minerals associated with it have replaced diopside and other relatively high-temperature silicates of metamorphic origin. At the Tungsten King mine, dark-green hydrobiotite (β near 1.59, (−)2V very small) is the chief constituent of altered and metalized lamprophyre in the vein fissure (fig. 30).

Chlorite group (hydrous silicates of Mg, Fe, and Al).—Chlorite is a common alteration product in the igneous and metamorphic rocks and is associated with the replacement ores. The aluminous variety clinochlore occurs in the outermost zone of metamorphism near Johnson as small metacrysts in silty dolomite beds. A less aluminous variety, penninite, generally accompanied by actinolite and calcite, is intimately associated with most of the pyrometasomatic replacement ores.

Antigorite [$Mg_3Si_2O_5(OH)_4$].—Antigorite or serpentine is a retrogressive alteration product of forsterite and locally of tremolite and diopside, in the metamorphic rocks near Johnson. The mineral is particularly conspicuous in the lower and upper serpentine markers, which are persistent beds of ophicalcite in which bottle-green to pale greenish-yellow antigorite has replaced forsterite and tremolite respectively.

Talc [$Mg_3Si_4O_{10}(OH)_2$].—Silty dolomite pebbles and cobbles in the Glance conglomerate near quartz-galena veins in the Gunnison Hills have been altered to fine-grained talc and calcite in nearly equal proportions (fig. 29). X-ray and thermal analyses of the talc indicate an unusually pure variety of the mineral (G. T. Faust, oral communication, 1950). Talc has not been identified near Johnson, but a little of retrogressive origin is suspected in the white tactite and related rocks. The flakes are so small and so mixed with other minerals that distinction from sericite by optical methods is not possible.

Celadonite (silicate of Fe, Mg, and K).—Minute but conspicuous bluish-green needles and fibrous aggregates, identified as celadonite by Charles Milton, occur in vesicles and seams in the basaltic lava flow within the Threelinks conglomerate of the Steele Hills and locally in the andesite at the base of the Galiuro volcanics. The mineral is included in this summary because prospect pits suggest that it has been mistaken in the past for a copper mineral.

Clay minerals (hydrous silicates of Al and other bases).—Quartz-tungsten veins in the Texas Canyon quartz monzonite are bordered by a thin inner zone of greisenlike alteration and a broader less well defined outer zone of argillization. Concerning one specimen of the argillized rock examined in the Geological Survey laboratory, R. L. Smith reported (written communication, June 1948), "This specimen of quartz monzonite contains insufficient clay material for a dependable examination. Microscopic study in fragments and thin section was not decisive in differentiating between potash clay and beidellite. The mean index of refraction seems too high for beidellite and a little low for potash clay. Dr. Ross believes it more likely to be potash clay." The clay mineralogy of these altered zones was not pursued further. Soft white material resembling halloysite ($Al_4Si_4O_{10}(OH)_8 \cdot 4H_2O$) in optical properties was found filling vugs in one vein in the quartz monzonite. Clay minerals are generally scarce in the metamorphosed rocks near Johnson, but the hornfels derived from the lower shale member of the Abrigo formation is argillized on the 300 and 500 levels of the Republic mine. At the Peabody mine there are local small veinlets and disseminations of soft yellowish-green material identified by Charles Milton as a ferruginous clay related to nontronite.

Chrysocolla [$CuSiO_3 \cdot 2H_2O$.]—Green to blue chrysocolla is one of the most widespread and abundant of the oxidized copper minerals of the area.

Sphene [$CaTiSiO_5$].—Sphene is a common accessory mineral in both the igneous and metamorphic rocks. It occurs in all types of silicated carbonate rocks near Johnson as well-formed crystals of microscopic size.

COPPER-ZINC DEPOSITS

BEDDED REPLACEMENT DEPOSITS

Pyrometasomatic copper-zinc deposits, formed by the selective replacement of favorable beds, are found in the metamorphosed carbonate rocks near the Texas Canyon quartz monzonite stock. Evidence of metalization and some important ore bodies occur as much as 8,000 feet from the nearest known contact of the stock. The only production of consequence has come from the Johnson Camp area shown on the detailed geologic map (pl. 6). The deposits in other parts of the metamorphic aureole are generally too small and low grade to mine, though a little ore has been shipped from the area west of Dragoon.

The ore bodies at Johnson are either tabular deposits parallel to the beds or chimneys which are generally oval in cross section and have their long axes and intermediate axes in the plane of the beds. Chimneys whose long axes lie at a large angle to the dip direction of the beds are known locally as mantos. The largest chimney mined up to 1957, the Main Manto of the Republic mine, was 1,500 feet long, 30 to about 100 feet wide, and 15 to 40 feet thick. It had several large lateral extensions in the form of tabular bodies in the plane of the beds. Chimneys in the Moore mine have diameters as great as 60 or 70 feet. The largest tabular ore body so far found, Northeast Winze ore body of the Republic mine, was about 800 feet long (parallel to plunge), 200 to 400 feet wide (parallel to the strike of beds) and 15 to 40 feet thick (perpendicular to beds).

The primary ore consists of varying proportions of chalcopyrite, sphalerite, pyrite, and bornite, and a little scheelite, magnetite, and molybdenite, in a gangue of lime silicates, orthoclase, chlorite, calcite, and quartz. Near-surface oxidized ores were important during the early history of the district but are of little importance at present. The depth of oxidation was less than 50 feet at most places but the lower limit is very irregular, and some oxidation effects are evident along water courses at the deeper levels. Supergene sulfide enrichment is completely absent from ores on the deeper levels and appears to have been slight even at shallow depths. The typical ore is low in pyrite, and hence there never was a large amount of acid to leach copper from the oxidized zone. In most places the dissolved copper was soon redeposited as carbonate or silicate by the neutralizing effect of the calcite-rich environment.

The grade of the ores has been somewhat variable. Data for the Peabody mine and other small deposits in the Carboniferous rocks of the northeastern part of the district show an average grade of about 7.5 percent copper, 4.5 ounces of silver, and 0.01 ounce of gold per ton. The ore from the Abrigo formation, mostly from the Republic, Mammoth, Copper Chief, and Moore mines, has been of lower grade. In the period 1904–40 it contained 4 to 4.5 percent copper and 0.50 to 0.75 ounce of silver per ton. The zinc content is not known. Since 1940 the ore mined has contained 1.5 to 3 percent copper, 5 to 10 percent zinc, and about 0.3 of an ounce of silver per ton. In general, the heart of an ore body is relatively high in copper, whereas the fringes are high in zinc. The zinc content varies more erratically than the copper content. The ores characteristically contain about 0.1 percent tungsten trioxide which has not been recovered.

The origin and localization of the deposits have been discussed in general terms in the section on igneous metamorphism. The remainder of this section will be devoted to further discussion, with specific illustrations, of those aspects of most use in exploration and development. Experience has shown that these are primarily stratigraphic (favorable beds) and secondarily structural (fissures and folds).

FAVORABLE BEDS

At least 95 percent of the ore so far found in the district has been in the middle member of the Abrigo formation. This member has yielded all the ore from the Republic, Copper Chief, and Mammoth mines, and nearly all the ore from the Moore mine. The principal ore bodies have been at the top of the middle member, in unit 5. Several of the largest bodies have extended into the upper part of unit 4.

The factors that make unit 5 favorable for ore include a contrast with the overlying beds in lithology and physical properties. The overlying white tactite is a uniform and competent structural unit compared with the erratically garnetized limestone below. (See fig. 9.) Moreover, the limestone was garnetized after the white tactite was formed—that is at a higher intensity stage of the progressive metamorphism. Therefore, losses in volume that accompanied garnetization probably formed relatively open permeable ground below the competent "roof" of white tactite. The white tactite would maintain openings best immediately below it, and the effect would decrease downward. In addition to this effect, the white tactite probably dammed and channelized ascending solutions during garnetization and later metalization. All these effects would make unit 5 favorable for ore.

The lithology of unit 5 probably contributed to its favorability for ore. The unit is characterized by thin but persistent beds of coarse-grained limestone interbedded with layers of shale or sandstone of about the same thickness. At places the limestone beds can be traced into high-grade garnetite ore, whereas the intervening clastic beds pass into barren garnetite. The ore bodies are characterized by such high-grade and barren bands 2 to 12 inches thick. Alternates 2- to 12-inch beds of limestone and terrigenous clastic rocks appear to be favorable for deposits of ore, although the reason for this is obscure. The desirable lithology characterizes most of unit 5 but is rarely present in other units or formations.

Some parts of unit 5 lack the most favorable lithology, and these parts were less readily metalized. Some lateral extensions of the Main Manto ore body of the Republic mine were in two sets of beds separated by so much waste that they were mined separately. The full thickness of the 467 ore body at the Mammoth mine was not appreciated until mining was far advanced, because a thin layer of waste concealed a thick mass of ore beneath the floor of the original stope. It is easy to overlook valuable ore when only part of the favorable unit is explored.

In and southeast of the Republic mine, small ore bodies have been found in unit 2 or 3 of the Abrigo, more than 100 feet stratigraphically below the main ore-bearing beds. The known occurrences are the West Manto and 700 Station ore bodies of the Republic mine, the shallow ore bodies mined many years ago on the Chicora and Southern claims, and low-grade ore discovered by drilling on the St. George claim. The lower ore in the Republic mine is directly below a mass of white tactite formed by local abnormal alteration of the calcareous rocks. This suggests that the localizing factors may have been in part the same as for the main ore bodies in the mine. No white tactite is found, however, at the other localities.

The shaly beds of the Horquilla limestone have been much silicated and have yielded an unknown amount of ore from the Peabody mine, the Mackay, Black Prince, and other workings. Surface and accessible underground workings indicate that most of the ore was localized by thin favorable beds but some of it was along transecting fissures.

Other stratigraphic zones have yielded very little ore. A negligible amount of sulfide ore has been taken from white tactite of the upper member of the Abrigo formation in the Moore mine and a little oxidized ore from the quartzite at the top of the formation in the O. K. mine. The Martin formation has yielded small quantities of oxidized ore from two horizons—namely units 1 and 2 on the St. George claim and in an open-cut 300 feet northeast of the Mammoth shaft and from unit 6 at the Moore mine. The ore at the Moore mine was practically free from contact silicates and generally contained 10 to 20 percent copper. The scarcity of ore in the Escabrosa limestone is remarkable in view of the favorability of this formation and its correlatives in other mining districts in the Southwest. The only production that can be established for the formation at Johnson Camp is a shipment of high-grade ore from a small pocket on the Copper King claim 900 feet north of the Republic shaft.

FOLDS AS LOCALIZING STRUCTURES

The Paleozoic rocks near Johnson strike northwest and dip about 40° NE. Slight undulations in strike and dip are evident at the surface (pl. 6) and in some of the mines Baker (1953, p. 1273–1274) recognized two sets of shallow warps, the Manto folds and Winze folds, that he believed were of great importance in localizing both garnetite shoots and ore bodies. "The axes of the two sets of folds are at right angles to each other: the Manto folds trend between due east and S. 70° E. and plunge 15° E. while the Winze folds trend about N. 10° W. and plunge 30° N." (Baker, 1953, p. 1274). The folds known to contain important ore bodies are so shallow and difficult to detect prior to mining that they are of little practical use in defining targets for exploration. There has been insufficient exploration to suggest whether large flexures had any effect in localizing ore. The most conspicuous of the large flexures are an anticline and syncline in the Mississippian and Pennsylvanian rocks east of the Keystone fault (pl. 6).

The clearest association of ore with a fold is in the Republic mine, where the Main Manto ore body lies along an anticlinal flexure between the 700 and 1300 levels. The West Manto ore body in the same mine follows a somewhat similar flexure. These relations probably are not fortuitious, but they are probably not essential controls for the manto ore bodies. The Main Manto fold dies out a short distance above the 700 level but the ore body continues with the same trend almost to the surface. As pointed out later, the underlying structural control of the Mantos is probably an eastward-trending fault. The ore-localizing structure may be the fault itself, an associated fold, or satellitic fissures that were open at the time of metalization. The ore-localizing structure is commonly obscure and seldom constitutes a recognizable target for exploration. The fault is generally easy to recognize, however, and by projection permits a general area of favorable ground to be defined.

One of the largest ore bodies so far found in the district, the Northeast Winze ore body at the Republic mine, was an elongate tabular mass plunging N. 10° W. in the favorable beds, oblique to all visible fractures. Its localization was never satisfactorily explained until Baker (1953, p. 1276) pointed out that its long axis lay along the axis of a broad and very shallow anticlinal flexure in the beds. This is the first Winze fold to be recognized and the only Winze fold for which a correlation of fold and ore can be established with any assurance. The relations on the St. George claim suggest that the mineralized ground found in drill holes 5, 10, 11, and 12 may be related to an anticlinal Winze fold indicated by the distribution of Abrigo and lowermost Martin units at the surface (pl. 11). Further underground exploration is the only way to confirm or disprove this speculation.

The A and B ore bodies of the Moore mine are similar to the Northeast Winze ore body in trend and in transecting relation to faults and fractures (fig. 31). No corresponding Winze fold is apparent in the mine workings (pl. 7). Some factor or factors other than folding seem to be involved in the localization of these ore bodies. They are near and roughly parallel to the Copper Chief No. 9 fault, which suggests that this fault may have prepared the ground in some unknown manner.

Ore body C of the Moore mine, unlike ore bodies A and B, is in a zone of obvious flexures in the beds. Changes in strike are evident on the 500 level; and flattening in dip is evident in stopes above the level, and in cross section (pl. 7). The changes in dip and strike are independent of one another and not the expression of a single plunging fold. The flattening in dip takes place along a horizontal northwestward-trending axis and is probably due to drag on the East 90 fault. The C ore body is a chimney in this fold. The changes in strike are due to other folds, which plunge steeply to the north. These folds appear to be Winze folds, but they were not mineralized.

The possible ore-localizing effect of a small fold in the Horquilla limestone could be tested easily at the Black Prince (Copper Bell) adit (fig. 34). Here a small but unusually sharp crumple in the beds is evident at the surface. The garnetite band, which is narrow at the surface, thickens and contains rich pockets of bornite near the projected position of the fold axis on the adit level. The bed has not been explored along the axis.

RELATION OF ORE BODIES TO FAULTS AND FISSURES

The fracture pattern in the metalized area near Johnson conforms to the regional pattern established prior to the intrusion of the Texas Canyon quartz monzonite. Faulting and fissuring were not confined to this early stage, however, but continued intermittently through the period of metalization; and some movements were even postore. The net displacement on most of the faults was of the normal type and resulted in right-lateral offset of the beds (pl. 6).

The faults and fractures in the metalized area fall into three sets locally called the Northeasters, Easters, and Northwesters.

In terms of abundance of individual fractures, consistency in attitude, and uniformity in direction of net displacement, the Northeaster set is the best developed. Hundreds of readily mappable fractures of this set are to be seen in the mines, and very few of these fractures depart as much as 10° from an average attitude of N. 17° E., 70° SE. The quartz-tungsten veins in the Texas Canyon quartz monzonite at the north end of the Bluebird vein system have the same attitude and project toward the Republic mine. No direct connection is apparent at the surface, however (pl. 6).

The Northeasters are marked by gouge and sheared rock, rarely by breccia, and very commonly by quartz-filled veins that in places contain potassium feldspar, fluorite, calcite, and base-metal sulfides. The zones of shearing are generally 1 inch to 2 feet wide but locally broaden into shear zones as much as 30 feet wide. Many are fissures without appreciable displacement. Others are normal faults resulting in right-lateral displacement of the beds. Those with stratigraphic throw exceeding 60 feet are very rare, but the Keystone fault has a throw of about 1,000 feet. Where Northeasters meet faults of the other sets, the Northeasters are generally offset; but there are many examples of the reverse relation and also proof of reactivation of faults of one set after they had been offset by a fault or faults of another set.

Many Northeasters have had no apparent effect on the localization of replacement ore bodies but others have been of great importance. The Republic, Mammoth, and Copper Chief mines were opened on tabular ore bodies that were exposed at the surface and were localized primarily by the favorable beds and secondarily by Northeaster faults and fissures. The importance of the fissures is shown by their abundance in the stopes now accessible and more significantly by the fact that the ore was in places notably thicker and extended deeper along them. Very little ore remains in the walls of these stopes. At the Mammoth mine one of the prominent Northeasters, the 467 fault, localized an important ore chimney at a slightly deeper level (pl. 7 and fig. 31). Here, as in several other examples of fault control in the district, the ore body was confined to the footwall side of the fault. Several lateral extensions of the Main Manto ore body at the Republic mine were localized by Northeasters at least in part. The large Northeast Winze ore body appears to have been localized by a shallow fold, but a chimney of high-copper ore occurred within the ore body along the No. 3 (Northeast Winze) fault, a typical Northeaster (pl. 9). No commercial ore bodies localized by Northeasters have been found in the Moore mine.

Faults and fissures that are classified as Easters are variable in strike and dip. The strike ranges from N. 60° E. to S. 60° E. and averages a little north of east. The dip is invariably to the south, opposite the dip direction of the beds. Most of the Easters dip 30° to 50° S., but some dip about 75° S. All the low-dipping Easters with determinable displacement are normal faults; but two of the steep Easters, the 1400 and 1600 faults in the Republic mine, are reverse faults. Displacements are generally less than 40 feet, but locally exceed 100 feet on the 1600, Mammoth, and East 90 faults, and 250 feet on the Republic fault.

Some small Easters cutting the Martin and Escabrosa formations are silicified and contain ore minerals; but the large Easters are not so mineralized. They are marked rather by as little as an inch of gouge to as much as 30 feet of gouge and sheared rock. Large Easters are therefore rarely exposed at the surface, and they frequently cause blocky caving ground in mine workings. According to Baker (1953, p. 1273), who studied the deeper levels of the Republic mine opened after our detailed work:

> Where the faults pass through ore bodies, this main zone is in places bordered by a zone in which the wall rock has been shattered and then partially replaced by chlorite along the fractures. The chlorite in these zones is sheared like that of the zones of major movement, but the wall-rock fragments have been neither rotated nor moved any appreciable distance. In rare instances, at or near the intersections of the Easter faults with ore bodies, chalcopyrite occurs in the fault zones, intergrown with unsheared chlorite.

The manto ore bodies so far discovered in the district are near Easter faults, as illustrated on the block diagram of the Moore mine-Mammoth mine area (fig. 31). The large C and D ore bodies are in the favorable beds abutting the north or footwall side of the East 90 fault, which clearly was the localizing structure. A small but high-grade ore body was localized by the same fault in the Martin formation (pl. 7). The fault was probably the feeder for the B ore body. Since the illustrations were prepared, ore has been found in the favorable beds of the Abrigo on the south or hanging-wall side of the fault, in the block west of the No. 9 fault.

The Old Manto ore body (pl. 7 and fig. 31) illustrates a more common though less obvious kind of relation with an Easter fault. The long axis of this ore body is parallel to the Old Manto fault but is in the footwall about 50 feet from the fault. Small Easter fissures, probably steeper than and satellitic to the main fault, are to be seen here and there in the roof of the stope and probably localized the ore body. Many years ago a little ore was taken from the Martin formation along the Old Manto fault at the surface above the manto.

The manto ore bodies at the Republic mine (pls. 8, 9, 10) were related to the Republic fault in the same way that the Old Manto ore body was to the Old Manto fault. The Main Manto ore body followed the Republic fault for 1,500 feet but was 100 to 200 feet down-dip from it in the favorable beds. Above the 700 level the ore body appears to have been localized along satellitic Easter fissures as was the Old Manto ore body. Below the 700 level it was localized along an anticlinal flexure in the beds. The West Manto was adjacent to the Republic fault at the upper end and about 80 feet from it at the lower end. No ore is known along the main zone of movement of the Republic fault, but a small amount of rich copper ore was mined along steep Easter fissures near it on the Copper King claim.

Each of the manto ore bodies has a similar spatial relation to an Easter fault that is large enough to be detected readily by geologic mapping. Although the manto is not always directly along the main fault but may follow obscure minor structural features as much as 200 feet from it, the broad interrelation is too consistent to be fortuitous. Thus undiscovered mantos may well exist in the favorable beds beneath other large Easters in the district.

Northwester faults and fissures are very scarce compared with Northeasters and Easters. Northwesters characteristically strike about N. 10° W. and dip steeply either east or west. Silicification along them is rare, and they are generally marked by a few inches to a few feet of gouge and sheared rock. The Copper Chief No. 9 fault (pl. 6 and fig. 31), which has a stratigraphic throw slightly exceeding 100 feet at some places, is the only Northwester known that has more than a trivial displacement. The A and B ore bodies at the Moore mine are near and almost parallel to the Copper Chief No. 9 fault (fig. 31), and the Copper Chief ore body (fig. 32) was immediately adjacent to the same fault. There is no evidence to suggest that the fault was a channelway for metalizing solutions but it may have prepared the ground in some unknown manner. Baker (1953, p. 1274) pointed out that "* * * folds trend approximately parallel to the strike of the Northwester faults, but two of the Winze folds are 500 feet from the nearest Northwester fault, so a genetic relationship is doubtful."

Not every fracture in any set is a mineralizing fracture. A mineralizing fracture must be one that was in existence at the time of metalization, and at that time, it must have been permeable and sufficiently persistent to connect directly or indirectly with a source of metalizing solutions. To have localized an ore body of consequence, the fracture or fracture system must have been large enough to channelize a significant quantity of ore-forming solutions. As yet there is no reliable way to recognize the fractures that satisfy these requirements. The criteria that have been used include the presence of quartz, limonite, and ore minerals in or along the fracture. The presence of ore minerals, even if only in traces, is the most obvious and probably the best of these criteria. Even in oxidized outcrops, the criterion can be applied with considerable assurance. Supergene leaching and transportation of metals has been slight because of the carbonate-rich environment. If sulfides were ever present, their oxidized equivalents are likely to be preserved near the point of original deposition.

Geochemical analyses of 60 samples from fault zones near the Moore mine have shown that the ore-metal content may exceed 0.2 percent without ore minerals being visible, and that the content varies considerably with little regard to any visible characteristics of the fault zone (Cooper and Huff, 1951, p. 748–750). Clearly, geochemical techniques are a powerful aid to visual examination in attempts to recognize and appraise mineralizing fractures.

Geochemical prospecting methods are a well known tool to detect and locate the source of metals that have been dispersed by supergene processes, but their application to hypogene dispersal patterns is less well known. It may be of interest therefore to compare the geochemical results (Cooper and Huff, 1951) with the results of subsequent exploration and development. The area of geochemical studies was near the Moore shaft and the A ore body, which was the only ore body then known in this area (pl. 6 and fig. 31). Geochemical anomalies were found above the A ore body and at two other places (Cooper and Huff, 1951, fig. 5).

Several later drill holes on and near one anomaly about 740 feet southeast of the A ore body have revealed only weakly metalized rock, but the important B, C, and D ore bodies have been found to the northwest (fig. 31), near the other anomaly. Geochemical prospecting cannot take credit for the discoveries, but a genetic relation between the geochemical anomaly and the ore is suspected. The anomaly is in and adjacent to the Mammoth and Copper Chief fault zones, in the northernmost outcrops of bed rock. These outcrops are 100 to 300 feet northwest of the B ore body and slightly south of the C and D ore bodies. The Mammoth fault lies between these ore bodies and the surface in other parts of the area of geochemical study. It is possible that partly spent ore solutions were deflected by the Mammoth fault and did not pass through it toward the surface. This would explain why there is no geochemical anomaly directly above the B ore body. In general, geochemical prospecting for hypogene dispersal halos is a promising tool for detecting relatively favorable blocks of ground, although it cannot assure that ore-grade material is present.

Some postore faulting is proved conclusively by the presence of clastic fragments of ore in fault zones and by the displacement of late quartz-base metal veins. Probably most of the old faults were reactivated, for only a few preore shear zones are obliterated by alteration and metalization where they cross ore bodies. The largest fault displacement we were able to date positively as postore was less than 10 feet. Some postore movements may have been considerably greater than this for it is generally impossible to determine preore and postore movements on the larger faults, such as the Republic fault which clearly was active after the 700 Station ore body and late quartz-bornite veins were formed. The ordinary criterion of postore displacement, that is the offset of ore bodies along a fault, is not reliable; for the stratigraphic control of ore deposition was so strong that, after fault movement ceased, the same beds were mineralized on the two sides. Local miners commonly speak of the ore being thrown this way or that by a fault even though the fault movement was preore. Mining has shown in many places that the supposedly faulted segments do not match one another.

VEIN DEPOSITS

Veins that contain copper and generally some zinc and (or) lead are found in and around the Texas Canyon quartz monzonite stock, particularly in the vicinity of Johnson and west of Dragoon. Some sulfide-bearing quartz veins are 1 inch to 3 feet wide and have filled fissures. Others are impregnations and replacements of shear and breccia zones which are at most a few feet wide. The veins have been prospected at many places but have yielded little ore.

The Northeaster fissures near Johnson are commonly filled with narrow veins of quartz containing variable proportions of bornite, chalcopyrite, sphalerite, tetrahedrite, galena, pyrite, scheelite, potassium feldspar, fluorite, and calcite. Veins that are of ore grade are at most a few inches wide and thus are too small to mine. At the O. K. mine a small stope was opened along a steep northwestward-striking vein, 1 to 4 inches wide, consisting largely of sulfides (fig. 36). In the accessible part of the Peabody mine there is a small stope on an oxidized replacement vein in a typical Easter (fig. 33). Above the Copper Bell adit two small stopes were opened in what appear to have been replacement ore shoots adjacent to a typical Northeaster (fig. 34). There is almost no indication of metalization along the same shear zone on the adit level. The trivial importance of the vein deposits is truly remarkable in view of the probable importance of fissures in localizing bedded replacement deposits in the district.

At the Centurion mine 4 miles south of Johnson, there has been considerable exploration of a vein that follows a major fault separating the Pinal schist from limestone of Mississippian age (pl. 12). Where the fault cuts the Texas Canyon quartz monzonite a short distance north of the mine, it is represented by 5 to 10 feet of silicified rock that contains some oxidized iron and copper minerals and traces of supergene chalcocite. The part of the vein explored in the mine has Pinal schist in one wall and limestone in the other. Silicification is slight, but the shear zone contains iron oxides and a little malachite and chrysocolla to the deepest level, 520 feet vertically below the surface. The vein as a whole is very low grade. Most of the modest production from the mine probably has come from pockets along minor faults and fissures in the limestone, from supergene malachite coatings on limestone in solution caves, and from a small mass of garnetite adjacent to an aplite dike on the 100 level.

Other veins have been prospected in the Precambrian rocks and in the marginal part of the quartz monzonite stock southwest of Johnson and in the areas of Paleozoic rocks southwest of the Centurion mine. The only known production of copper ore from these veins is a single small shipment of fine-grained ore obtained by screening the material from a small low-grade quartz-bornite-chalcopyrite vein cutting the Horquilla limestone near the Empire No. 2 shaft west of Dragoon.

LEAD-SILVER VEIN AND REPLACEMENT DEPOSITS

Small vein and replacement deposits in the northern part of the Gunnison Hills have yielded 800 to 1,000 tons of oxidized lead-silver ore. Most of this ore came from the Texas Arizona mine, where replacement deposits occur in favorable beds and in fractured zones in the Escabrosa limestone (fig. 39). The Texas Arizona ore averaged about 40 percent lead and 50 ounces of silver per ton and thus was of excellent grade, but it occurred in small bunches and thin tabular masses that proved hard to mine profitably. It consisted of cerussite, anglesite, and residual galena in a gangue of quartz, dolomite, and calcite. Horn silver has been reported but none was found during our examination. Small pockets of oxidized zinc ore (willemite, hemimorphite, and hydrozincite) are found in broken ground near the lead-silver ore bodies, and probably represent zinc leached from the primary ore and redeposited by ground water. Replacement deposits like those at the Texas Arizona mine are extremely scarce in the Gunnison Hills area, and none of the others has yielded more than a few tons of ore.

Several miles north of the Texas Arizona mine, lead-silver veins 1 to 12 inches wide and a few hundred feet long cut the Glance conglomerate. These veins, formed by filling of minor fissures of east and northeast trend, consist in their unoxidized state of quartz, calcite, galena, pyrite, and chalcopyrite. The quartz appears to have grown out from the walls. The sulfides are later than the quartz which they replace, the calcite is coarse grained and fills vugs. Within about 20 feet of the veins, dolomite pebbles in the conglomerate are commonly altered to a soft chalky white aggregate of talc and calcite (fig. 29); the distribution of altered pebbles assists in finding and tracing veins. In the outcrop, the sulfides in the veins have been largely oxidized to anglesite, cerussite, limonite, malachite, and chrysocolla. Small shipments of hand-sorted ore have been made from pits and shallow shafts.

Although the lead-silver deposits of the Gunnison Hills are the only deposits of this kind that have been worked in the district, there are other indications of a concentration of lead and silver in the outer part of the metamorphic aureole north and east of the Texas Canyon stock. This part of the aureole is mostly covered by alluvium, but the silver content of the pyrometasomatic replacement deposits generally increases with distance from the stock. Production records indicate that the silver content of the ores from the Republic mine-Mammoth mine belt, relatively near the stock, has been 0.3 to 0.8 ounce per ton and 0.1 to 0.2 ounce to 20 pounds (1 percent) of copper; the corresponding figures for the Peabody mine, farther from the stock, are about 4 ounces per ton and 0.6 ounce to 20 pounds of copper. There is almost no lead in the ores from the Republic-Mammoth belt, but locally there is as much as several percent in the ores from the Peabody area. A few small quartz-galena

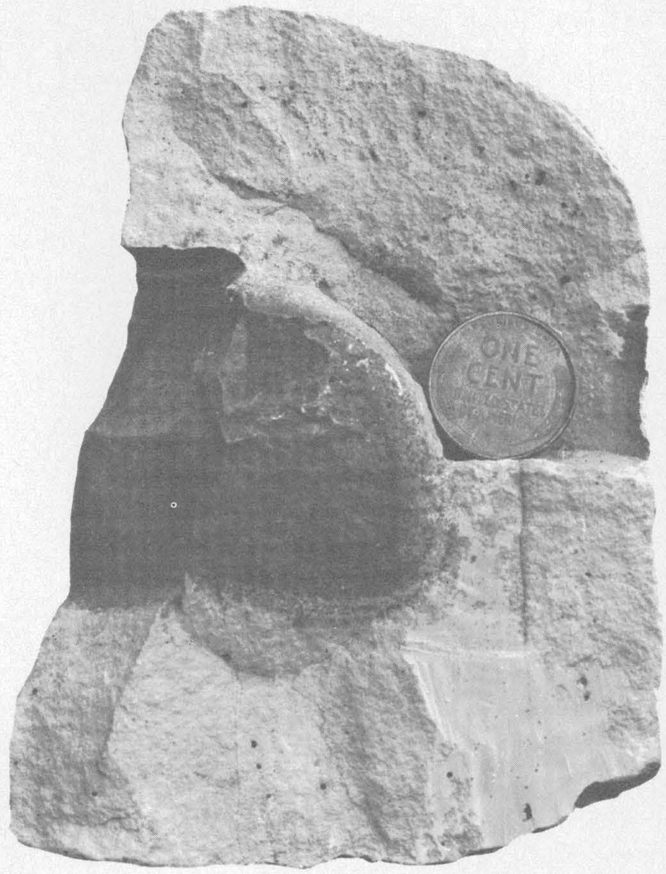

FIGURE 29.—Part of a cobble from the Glance conglomerate showing unaltered dolomite core and talc-calcite rim.

veins occur in the outer part of the metamorphic aureole west of Johnson. The same relations as at Johnson are suggested for the area west of Dragoon by two small ore shipments from that area. According to John Walker (oral communication, 1950), a 30-ton shipment he made from the Horquilla limestone near the contact of the quartz and monzonite south of the Fulton Ranch was considerably lower in silver than a 27-ton shipment made by O. T. Smith from the same formation where it is exposed south of the Southern Pacific Railroad tracks about a mile farther from the stock. There are a few small quartz-galena veins in the latter area.

TUNGSTEN DEPOSITS

Tungsten deposits in the Dragoon quadrangle consist of vein deposits, placers derived from the veins, and low-grade disseminated deposits. Quartz-huebnerite veins and associated placers in the northeastern half of the Texas Canyon quartz monzonite stock yielded a substantial amount of tungsten before and during World War I, and they are still worked from time to time on a small scale. A little scheelite and huebnerite has been produced from veins in schist and limestone near the quartz monzonite, and scheelite has been produced at the Tungsten King mine from a contact vein between the Tungsten King granite and the Pinal schist. Scheelite disseminated in the pyrometasomatic copper-zinc ores is of potential importance but has not been recovered up to the present time (1957).

VEIN DEPOSITS IN THE TEXAS CANYON QUARTZ MONZONITE

The tungsten minerals huebnerite and scheelite occur in veins of coarse-grained white to grayish quartz which cut the Texas Canyon quartz monzonite northeast of an arcuate line extending from the contact 2¾ miles west of Dragoon via the Triangle T Ranch to the contact north of Adams Peak. Southwest of this line, tungsten minerals were not detected in veins that seem identical in other respects. No explanation for the apparent geographic restriction of tungsten mineralization can be offered.

A few tungsten-bearing veins are 1,000 to 2,000 feet long and locally as much as 6 feet wide, but these relatively large veins have not been very productive. Most of the ore has come from veins less than 2 feet wide and less than 300 feet long—too small to show individually on the scale of plate 1 but shown in part on plate 6. These veins, with few exceptions, are in the areas shown as altered quartz monzonite. The long narrow bands of alteration define complex vein systems, some of which extend in weakened form beyond the ends of the alteration zones mapped. The most productive vein system, called the Bluebird vein system, extends from the quartz monzonite contact south of Johnson for about 4,500 feet south-southwest and then follows a southwestern course for 2¾ miles, where it dies out (pls. 1, 6). Details of this system are presented in the description of the Primos and Little Fanny groups of claims, which cover it from end to end.

The veins are not uniformly mineralized but consist of nearly barren quartz with sporadic shoots containing from a few pounds to perhaps several thousand tons of ore. Some very rich pockets have been reported. For example, 4- to 5-ton masses of clean ore carrying 50 to 60 percent WO_3 were reported by Rickard (1904, p. 264), and a 1-ton chunk of nearly pure huebnerite is said to have been taken from the Bluebird mine (John Walker, oral communication, 1950). Fragments of rich float still to be found in the area lend credence to such reports, but no comparable concentrations are to be seen in the veins at present. Exposed ore shoots seem to have been mined out though the scarcity of visible ore may be due in part to the fact that lessees and others who have worked the deposits have made a practice of covering up faces of ore when mining was suspended (E. C. Walker and J. J. Wien, oral communications, 1950).

The Bluebird and other linear vein systems—which probably are the expression of major fissures in depth—generally consist of a complex of short en echelon veins, fractures, and shear zones, some of which strike nearly parallel to the containing system and others are at large angles to this trend. The great preponderance of veins strike in the northeast quadrant and dip southeast. The pattern made by one or more sets of veins at a particular locality is characteristic of long segments of that system and commonly is characteristic for the full length.

The vein systems represent structural elements that were formed after regional jointing of the quartz monzonite. The joints are preaplite for aplite dikes have been intruded along them; whereas the fractures in the vein systems have not been loci for aplite intrusions. Veins cut aplite at many places. Joints mineralized by seams of quartz and tungsten minerals are present but scarce.

The veins were formed mostly by the filling of open cavities and only to a very minor extent by replacement. All appear to be younger than the aplite. They appear to be older than the lamprophyre, for lamprophyre dikes were found cutting quartz veins at two places and no examples of the reverse relation were observed.

There is abundant evidence of repeated fault movements in the vein systems during the period of mineralization. Some veins are sheared, others unsheared, and a few consist of an earlier sheared part and a later unsheared part. Tungsten minerals are about equally abundant in sheared and unsheared veins and are themselves deformed where the containing gangue is deformed. Many veins have more than one direction of striae indicating movement at different times and in different directions. At some places the veins, both sheared and unsheared, are offset a few inches along small barren faults.

Evidence of the direction of fault movements includes the fracture pattern as a whole, slickensides and striae on particular planes of movement, and the relation of subsidiary shear planes to the main planes of movement. The evidence, presented in detail in the descriptions of individual mines and prospects, suggests both reverse and normal movements generally but not invariably involving a right-lateral component. The blocks outlined by the vein systems were jostled this way and that with the net effect of a westward displacement on the south. The total displacement along the vein zones was probably not great as there is no continuous fault along any of the zones nor any appreciable offset of the border of the quartz monzonite on their projection.

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MINERALOGY

The hypogene minerals of the veins include quartz, muscovite, fluorite, huebnerite, scheelite, small quantities of the common base-metal sulfides, traces of apatite, and rarely calcite. Quartz is the predominant mineral. It is white to light gray and coarse grained. Small vugs lined with clear quartz crystals are common, and crystals of scheelite, base-metal sulfides, and supergene minerals are found in these vugs.

Pale-green muscovite in tabular crystals a quarter of an inch or less in diameter is widespread and relatively abundant. It very commonly forms selvages along the sides of the veins; in unsheared veins the plates stand perpendicular to the vein walls. It occurs also as veinlets and lenses in the quartz and as films along shear planes. Some ½- to 1-inch veins are mostly muscovite. The selvages of muscovite are commonly the only mineral banding in the veins.

Other nonmetallic minerals are erratic in occurrence. Fluorite, which is colorless, pale blue, pink, or deep purple and generally nonfluorescent, occurs in scattered grains and aggregates locally as much as a foot long but generally smaller. Colorless apatite that fluoresces orange-yellow occurs in scarce stubby prisms as much as half an inch long in the veins and is common in the altered wallrock next to them. The hypogene calcite is brown and occurs as cleavable masses in the quartz.

Muscovite and fluorite are the only nonmetallic minerals that seem to have any possible relation to ore occurrences. They are generally conspicuous in the ore-bearing veins, and some ore bodies occur where one or the other is concentrated. Both are more widespread than the ore, however. Neither apatite nor hypogene calcite is concentrated in the ore veins. Calcite seems more abundant in the barren veins.

Huebnerite is the principal ore mineral except in some veins southwest of the Centurion mine. It occurs in tabular prismatic crystals from an ⅛ to nearly 6 inches in length. Nearly all of it is embedded in solid quartz, but some is embedded in muscovite and a few blades were found along the cleavage planes of fluorite. Huebnerite has no generally prevalent pattern of distribution in the veins but is in part central, in part disseminated from side to side, and in part in marginal layers and bunches.

Scheelite is an important, though subordinate, mineral in the Bluebird area. The scheelite is not confined to the veins but is also sparsely disseminated in the altered quartz monzonite next to them. Some of the scheelite is in fine-grained white aggregates that have partly replaced huebnerite; the rest is in pale-brown dipyramidal crystals, as much as an inch in diameter, embedded in massive quartz, encrusting quartz crystals in vugs, and included in the glassy quartz crystals of the vugs. A little of the scheelite is green because of microscopic inclusions of cuprotungstite. Nearly colorless scheelite is the only tungsten mineral present in veins near the quartz monzonite-limestone contact southwest of the Centurion mine. Apparently the tungsten-bearing solutions dissolved enough calcium from the limestone to form scheelite to the exclusion of huebnerite. According to Kerr (1946, p. 33–34), tungsten has an affinity for calcium that results in the formation of scheelite where the requisite calcium is available.

Pyrite, chalcopyrite, galena, and sphalerite are common but very minor vein constituents. They occur as vug fillings and as sparse disseminations. The pyrite is generally in well-formed cubic crystals and less commonly in complex forms. The sphalerite contains oriented microscopic rods of chalcopyrite, and their uniform distribution suggests an origin by exsolution. The galena has octahedral parting and peculiar satiny luster due to the presence of bismuth in the form of microscopic oriented blades of tetradymite. The base-metal sulfides appear to be the last hypogene minerals formed in the veins. They are more widely distributed than the tungsten minerals and are not appreciably more abundant in the veins that carry tungsten.

The supergene minerals include the familiar iron oxides; the copper minerals chalcocite, covellite, cuprite, and malachite; silica in the form of crystalline quartz, chalcedony, and opal; calcite that fluoresces pink to fiery red; willemite, wulfenite, mottramite, and pyrolusite. These minerals are generally scarce and only the last two require comment other than the notes given in the summary of minerals.

The pyrolusite, possibly accompanied by other manganese oxides, generally occurs as stains, dendrites, or soft crystalline crusts on exposed surfaces, or in cracks and vugs in the veins. However, in an opencut about 1,000 feet southeast of the Little Fanny mine, hard crystalline masses of the mineral are embedded in quartz without clear evidence of how surface waters reached the masses or why they are localized where they are found. It is possible they are of hypogene origin.

Mottramite is conspicuous and fairly common as thin olive-green crusts on exposed surfaces and cracks. It seems to be abundant only in veins carrying tungsten—suggesting that the vanadium in the mottramite was derived from an unknown hypogene mineral having virtually the same distribution as the tungsten minerals. We have frequently observed mottramite and, on further search, found huebnerite or scheelite in the same vein.

WALLROCK ALTERATION

The quartz monzonite is altered for a few inches to a few tens of feet on the sides of the veins. Two zones of alteration are recognized: an inner zone generally only a few inches wide characterized by abundant muscovite and a wider outer zone of weak argillization. The rock of the inner zone is resistant to erosion and forms rusty outcrops. The argillized rock is nonresistant and is generally covered by angular rubble from the inner zone and the vein. These surface features contrast with the rounded uniformly pale-brown outcrops and sandy weathering products of the unaltered quartz monzonite. The vein systems and altered rock associated with them are commonly more resistant than the adjacent unaltered intrusive and form low ridges.

As a vein is approached, the first alteration effects evident are a slight clouding and dulling of the feldspars, particularly plagioclase. In the inner part of the argillized zone, the feldspars are chalky white and so soft that the rock crumbles readily to sand. Biotite in the rock appears to be unaffected, for it remains black and lustrous throughout the zone.

The rock of the thin inner zone is hard, lustrous, and lacks biotite. It grades abruptly into the most argillized part of the outer zone. The distribution and general character of the two zones are similar to those next to the tungsten veins of Boulder County, Colo., described by Lovering (1941) who used the descriptive term "casing" for the inner zone. As he (Lovering, 1941, p. 234) pointed out, the casing somewhat suggests a layer of fresh granite separating the vein from a wider zone of strongly altered granite, which in turn grades outward into fresh rock. The casings in the Little Dragoons appear to have been so interpreted by Rickard (1904, p. 263–264), who stated that dikes of granite, granite porphyry, and quartz diorite were intimately and directly connected with the ore deposits. That the casings were formed by alteration of the quartz monzonite is shown clearly by the field relations and petrography of the rock.

The casing rock in the Little Dragoons displays various degrees of muscovitization and silicification. Clay minerals are absent except in the extreme outer edge of the zone. Biotite is also absent except near the outer edge, having been replaced by muscovite, very commonly as unit pseudomorphs with intergrown microscopic grains and laminae of pyrite. Evidently sulfidation of iron liberated from biotite accompanied the muscovite-forming reaction. Plagioclase was replaced to a great extent by muscovite, which generally is in small plates with random orientation but locally is in large individual crystals which have their cleavage planes parallel to 010 of the host. The remaining plagioclase is clear albite. Orthoclase and microcline are turbid and commonly replaced by quartz, which in some specimens forms irregular blebs within the orthoclase and microcline crystals. Accessory magnetite was partly oxidized to hematite, but accessory zircon and apatite appear to have been unaffected. A little pyrite or its weathering product, limonite, is common in disseminated grains visible in hand specimens. Much of the contained iron doubtless came from the decomposition of biotite, but some may have been introduced by the altering solutions or derived from magnetite. A little fluorite occurs in seams of quartz and muscovite and in altered plagioclase and biotite. Fairly large grains of fluorescent apatite and scheelite occur in the most altered parts.

At most places the alteration did not completely obliterate the original texture of the rock though it is partly destroyed by the growth of new minerals and by strain effects. Strain effects are rarely noticeable in the field but are obvious in thin sections in the form of quartz with undulatory extinction and incipient mortar structure, feldspar crystals that are warped and broken, and muscovite plates that are bent. Undeformed muscovite that fills fractures in specimens full of deformed muscovite indicates deformation during the mineralization, the same as in the veins themselves. At some places next to the vein, the original texture is not only destroyed, but the altered rock has a foliation parallel to the vein. At such places the rock consists of muscovite, quartz, fluorite, fluorescent apatite, pyrite, and scheelite.

The altered areas shown on the geologic map (pl. 1) are, of necessity, generalized. The effects of alteration next to a single vein are not wide enough to show on the scale of the map, and thus it is only where many veins and seams occur close to one another that overlapping and merging small bands of alteration give an altered area large enough to map. The boundaries of the altered areas were drawn at those outcrops of biotite-free casing rock which best delimit the area as a whole. At many places, small areas of fresh quartz monzonite have been included within the altered areas and small areas of altered rock have been excluded.

ORIGIN AND LOCALIZATION OF THE DEPOSITS

The tungsten deposits probably were formed by late-stage emanations from deep within the quartz monzonite stock. Major fissure systems that may extend to great depth provided channelways for the mineralizing solutions, which altered the quartz monzonite and formed the veins. The deposits were formed at a high temperature. The vein and alteration minerals tend to be coarse grained. The walls of the veins are impregnated with fluorite and apatite, and the apatite fluoresces like that said to be common in pegmatites and cassiterite veins but not elsewhere (Ulrich and Maly, 1940). Even the youngest hypogene minerals in the veins appear to be of a high-temperature type (sphalerite with exsolved chalcopyrite and galena with exsolved tetradymite).

The mineral association and texture of the altered wall rock immediately adjacent to the veins suggests greisen though no tin minerals, tourmaline, or topaz have been detected. In other respects the alteration is similar to that common near veins formed at moderate temperatures. Excellent examples of similar alteration phenomena are near the ferberite veins of Boulder County, Colo. (Lovering, 1941), and near the base-metal veins at Butte, Mont. (Sales and Meyer, 1948).

The ore bodies are irregular in size, shape, and distribution. Both Rickard (1904, p. 264) and Richards (1908, p. 93) stated that the shoots rake about 40° N. in the plane of the veins, but this is not now evident in exposures or accessible stopes, which are irregular and less than 100 feet in the longest dimension. Wilson (1941, p. 42) stated that the shoots appear to occur where fissures of northerly strike intersect the veins, and that they may also be related to abrupt pinches or convergences of the vein walls. At several places we noted a concentration of ore minerals near a change in dip or strike of the vein and also near some but not all vein intersections. All the controls are tenuous and of little practical value as guides for exploration. Any complex of quartz veins that are part of a system known to carry tungsten must be regarded as favorable ground. The most productive veins generally crop out along the northwest or footwall side of the low ridges that mark the vein system.

VEIN DEPOSITS IN THE PRECAMBRIAN AND PALEOZOIC ROCKS

AREA BETWEEN DRAGOON AND JOHNSON

The Pinal schist within 1,000 feet of the Texas Canyon quartz monzonite southwest of Johnson is cut by several steep fissures that trend east-northeast and are filled with quartz-huebnerite veins resembling those within the quartz monzonite. The individual fissures persist for several thousand feet, but mineralization was confined to segments 100 to 800 feet long and rarely as much as 2 feet wide. The veins, here called the Donna Anna veins (pl. 6), have been opened by about a dozen opencuts and shallow shafts which probably have yielded a small tungsten production.

The Donna Anna veins have a more easterly trend than those at the north end of the Bluebird vein system and would intersect this system in the vicinity of Johnson. Though both vein systems appear to die out about half a mile from the point of convergence, the fissuring may continue in depth and be one factor in the localization of the Johnson Camp base-metal deposits. The abundant Northeaster veins near Johnson have the same attitude as the veins at the north end of the Bluebird system and contain scheelite and huebnerite locally. The veins near Johnson are much below tungsten ore grade however.

Streaks and disseminations of scheelite without associated huebnerite occur in small quartz veins cutting formations of Paleozoic age southwest of the Centurion mine. The only known production is about 500 pounds of scheelite concentrates from a small vein in the Horquilla limestone 700 feet west of the Empire No. 2 shaft. The vein, which is 4 to 18 inches wide, strikes N. 50° E. and dips 75° to 80° NW. It consists of coarsely crystalline grayish-white quartz, buff to deep-brown calcite, irregular grains of straw-colored scheelite, locally abundant pyrite and galena and traces of sphalerite, chalcopyrite, and chalcocite. The sulfides are younger than the scheelite and were deposited in part on deeply corroded quartz crystals in vugs. The galena lacks exsolved tetradymite.

The scheelite in this vein is conspicuous because of its coarse crystallization and straw-yellow color. The scheelite in other veins of this area is generally colorless and difficult to detect without an ultraviolet lamp. It is not present in every vein, but is widespread and occurs in small rich pockets at some places. No association with base-metal sulfides is evident. The richest concentration we observed is a lens 4 inches wide and 5 feet long in the vein shown on plate 1 cutting the Horquilla limestone near the Texas Canyon quartz monzonite 2½ miles west of Dragoon. Between this locality and the Centurion mine there are many scheelite-bearing veins within a few hundred feet of the quartz monzonite.

The deposits in Precambrian and Paleozoic rocks and those within the quartz monzonite have a common overall pattern of distribution and probably were formed by solutions from the same ultimate source in the quartz monzonite mass. The deposits in the igneous rock are consistently of the high-temperature type as shown by the texture and mineralogy of the veins and associated bands of greisenlike alteration. The deposits in the wall rocks were formed in an outer zone and in a different environment. Galena in these veins lacks the octahedral parting and exsolved tetradymite characteristic of the vins in quartz monzonite. Scheelite increases in abundance with respect to huebnerite in the calcareous rocks and is generally the only tungsten mineral where the veins cut unsilicated limestone. The walls of these veins are not conspicuously altered. A little silica and scheelite have been introduced into limestone next to some of the veins, and traces of fluorescent apatite were found near several veins in the Pinal schist near the quartz monzonite.

TUNGSTEN KING AREA

Scheelite-bearing veins were discovered in 1913 on the west side of the Little Dragoon Mountains near the present Tungsten King mine. Mining on a small scale has been carried on at intervals by several operators. Reported production to October 1954 was about 12 tons of scheelite concentrates, most of which came from the Tungsten King mine.

The principal deposit is in the King vein, another name for the Tungsten King fault, which here trends near north, dips 30° to 55° E., and separates Tungsten King granite on the west from Pinal schist on the east. For more than a mile south of Hughes Canyon, this fault is extensively but not continuously mineralized by quartz and small quantities of scheelite, beryl, pyrite, galena, sphalerite, and chalcopyrite. The mineralized segments, formed mostly by fissure filling but in part by replacement, are 50 to about 1,000 feet long and from 2 to 10 feet in maximum width. At places the quartz contains inclusions and septa of the wallrock. Near the Tungsten King mine the quartz intimately injects dark-green hydrobiotite schist which represents a thin lamprophyre dike intruded along the fault at an earlier stage.

The quartz is grayish white and coarse grained. It contains a little muscovite, albite, and microcline locally. Small pockets of pale-brown calcite are common.

Scheelite is in colorless to pale-brown disseminated grains 0.1 mm to 2 cm in diameter. It fluoresces blue white and, therefore, is a pure form of the mineral. Like beryl and pyrite it is not confined to the quartz but occurs also in inclusions and septa of wallrock. It is widely but not uniformly distributed in the vein. The largest known concentration is at the Tungsten King mine where an ore shoot several hundred feet long and about 3 feet in average width has been mined between the adit level and the surface, a vertical distance of about 100 feet. The shoot extended down the dip of the vein without evident change in thickness or character. Available assays and past production suggest that it averaged about 0.5 percent WO_3.

Pale-blue to colorless beryl is a very minor and erratic vein constituent which occurs in irregular grains 0.5 to 5 mm in diameter and in slender prismatic crystals as much as 2 cm long. It is commonly most abundant in parts of the vein which contain feldspar and seems to be unrelated to scheelite in distribution. Spectrographic analyses of eight channel samples of the vein in and near the Tungsten King mine showed between 0.0008 and 0.052 percent BeO and averaged 0.014 percent BeO.

A little pyrite, galena, chalcopyrite, and sphalerite are widely distributed in the vein in disseminated grains and small aggregates. The pyrite is generally in well-formed cubes, and the other sulfides are commonly molded over it. The galena, which is generally more abundant than either chalcopyrite or sphalerite, contains exsolved tetradymite as it does in the veins cutting the Texas Canyon stock.

Postmineralization deformation of at least two ages has affected the King vein. The earlier was of the plastic type and is expressed by locally developed schistosity in susceptible vein minerals and by distortion and rupture of some constituents. Figure 30 shows two

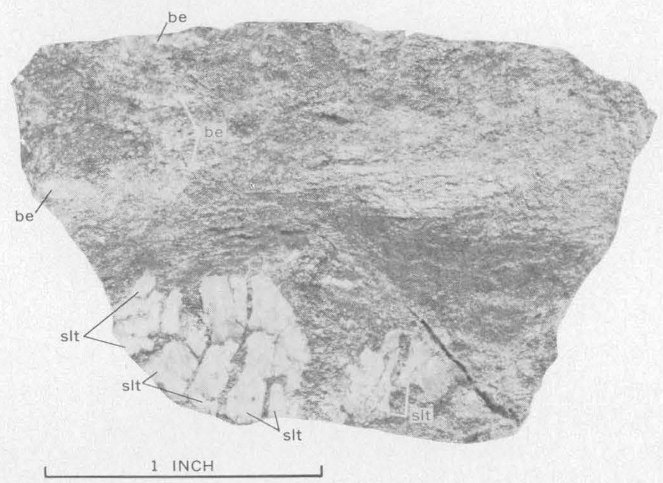


FIGURE 30.—Hydrobiotite schist containing disrupted scheelite (*slt*) and beryl (*be*) crystals that have been broken and pulled apart by flowage of the schist. From dump of Tungsten King mine.

scheelite crystals that were broken and pulled apart by flowage of the enclosing schist. The fractures in the scheelite are perpendicular to the lineation in the schist (horizontal in photograph), and the separation of scheelite fragments indicates a postscheelite lengthening of 10 to 15 percent in the direction of lineation. Scheelite and beryl crystals in quartz are locally broken and pulled apart also, but the quartz shows little evidence of deformation beyond a weak sheeting structure and many minute fractures that may have been planes of movement. The calcite and some of the galena have warped cleavage surfaces.

These deformation effects must have formed under considerable confining pressure and were probably caused by reverse movements in the vein zone. Schistosity in the vein material is generally very difficult to detect and measure, but at several places it is slightly steeper than the vein itself, suggesting reverse movement of the walls. Earlier prevein reverse movement is suggested by thickening of the vein in its flatter dipping segments, which would be opened by such movements. The thickest part of the vein (10 ft) is a third of a mile north of the Tungsten King mine and dips 25° to 30° E.

Later normal-fault movements took place in the vein zone and on cross faults that offset the vein. The zones of movement are characterized by gouge and broken rock. Slickensides and striae in the vein indicate the east or hanging-wall side moved obliquely downward to the southeast. The lateral component of movement on the cross faults is not known.

Many small quartz veins cut the Tungsten King granite within half a mile to the west of the King vein. A few are parallel to the King vein but most have diverse generally steeper attitudes. These veins, like the King vein, contain some scheelite, beryl, and base-metal sulfides. They have been prospected at many places but are too small for profitable mining.

The tungsten deposits of the King and associated veins are high-temperature deposits probably formed about the same time as those in the Texas Canyon quartz monzonite but around a different channel of mineralization. The King vein is in a Late Cretaceous or early Tertiary fault, and mineralization followed intrusion of a lamprophyre dike that we regard as one of the family of dikes emplaced near the time of metalization in and near the quartz monzonite. The local shearing of the King vein is regarded as a postquartz monzonite phenomenon like the local but intense shearing of veins in the quartz monzonite and the development of schistosity in the altered wallrock next to them. The presence of the unusual galena-tetradymite intergrowth in both groups of veins suggests a genetic relation between them.

PLACERS

Placer deposits derived from the huebnerite veins in the northern part of the Texas Canyon quartz monzonite stock were worked extensively between 1898 and 1918. They probably have yielded half and perhaps more of the tungsten that has been produced from the area. Much of the production was by hand picking, panning, hand jigs, rockers, long Toms, and dry washers; the power concentrators built during World War I were operated in part on placer material. Since 1918 the production from placers has been negligible.

Many of the placers are of the eluvial type, being simply accumulations on the hill slopes below the veins. These slopes were once littered with rich ore fragments, some weighing as much as 500 pounds (Blake, 1899, p. 544). The surface has been picked over repeatedly through the years, but rich fragments are still found occasionally; the largest seen during our mapping weighed about 6 pounds. Small particles of the tungsten minerals have accumulated in the fine debris that mantles the lower part of the slopes, and these deposits have been worked here and there by shallow pits and cuts.

Placers of the alluvial type have been worked in Texas Canyon and Sheep Basin as much as a mile from the source veins. The intermittent streams in these basins are vigorously downcutting and are on or near bedrock. The streambeds contained rich deposits, which were mined during the early years of this century. The deposits were described as gravels that ranged from a few inches to 5 feet in thickness and that averaged 15 to 18 inches thick, with an inch or two of rich reddish-black sand close to the bedrock (Rickard, 1904, p. 264). Deposits of this type in Devils Basin, a small amphitheaterlike depression at the head of Texas Canyon 1¼ miles north of the Triangle T Ranch, are said to have yielded 70 tons of concentrates which averaged 68 percent WO_3 (Rickard, 1904, p. 264). The Devils Basin placers could have been derived from the Bluebird vein system, though only half of a 1,500-foot segment of the system is within the local drainage basin, and the vein deposits in this segment have not been very productive.

The placers in the present stream channels, which are now mostly worked out, were formed in part by reconcentration of material in alluvium capping an old pediment surface. Remnants of this cap are preserved as small sandy terraces in Devils Basin and are said to contain a narrow pay streak on or near the bedrock (J. J. Wien, oral communication, 1950). We observed coarse huebnerite particles in the pediment gravels at several places, some at considerable distances from the source veins. For example, there is a notable concentration of huebnerite in a moderate-sized patch of gravel 1¼ miles northeast of the San Pedro ranchhouse on the south side of Sheep Wash and about 100 feet vertically above the present stream.

Alluvial placers are practically unknown in the basins of Big Draw and Walnut Wash although these basins contain the most productive vein deposits and many eluvial placers. Concealed deposits probably occur in the main bedrock channels beneath the broad mantle of barren alluvium.

Mining of the placers is handicapped by the scarcity of water. Attempts at large-scale operation that have been made in the past have not proved profitable.

PYROMETASOMATIC DEPOSITS NEAR JOHNSON

As first noted by Larsen in 1918 (Hess and Larsen, 1922, p. 260), scheelite is disseminated in the copper-zinc ores near Johnson. The scheelite occurs in small- to medium-sized colorless grains scattered through the silicated limestone. Apparently it was formed at nearly the same time as the copper and zinc sulfides, for it is most abundant in the base-metal ore bodies. The scheelite is commonly in well-formed crystals and thus of indeterminate paragenetic position, but in places it is corroded by sphalerite and cut by sulfide-bearing veinlets.

Before the Coronado Copper and Zinc Co. started mining but after preliminary development work hundreds of channel samples were cut from exposed faces of ore in the Republic mine. A composite of these samples contained 0.11 percent WO_3, according to company officials. Virtually the same average tungsten content is reported in ores from the Mammoth and Moore mines.

Although the tungsten content is very uniform on the average, it is not uniformly distributed in detail. Observations with the ultraviolet lamp indicate that parts of every ore body are very low in tungsten, whereas other parts may carry about 1 percent. The richer parts are commonly associated with abundant sphalerite as noted by Larsen (Hess and Larsen, 1922, p. 260). Selective mining of the tungsten-rich parts is not feasible because of their small size and scattered distribution, but it is possible that a method will be devised eventually for the recovery of tungsten as a byproduct. In the concentrating methods used the scheelite goes out with the tailings. By the end of 1954, the tailings pond of the Coronado Copper and Zinc Co. probably contained several million dollars worth of tungsten at the 1955 price.

The scheelite found in deposits like those at Johnson commonly contains objectionable quantities of molybdenum which substituted for tungsten in the crystal structure. No chemical analyses of the mineral from Johnson are available, but the fluorescence color indicates that there are two varieties. One fluoresces a distinct yellow and was estimated to contain 1 to 2.4 percent molybdenum using the scheelite fluorescence analyzer. The other fluoresces blue to yellowish white and was estimated to contain 0.05 to 0.15 percent molybdenum. The high-molybdenum type was found southeast of the Republic mine. Concentrates of this mineral would be subject to a price penalty as 0.4 percent molybdenum is the allowable limit in first grade scheelite concentrates. The low-molybdenum type seems to be universal in the ores of the Republic, Mammoth, Black Prince, and Peabody mines. Thus, no price penalty for molybdenum is to be expected in scheelite concentrates prepared from these ores unless the concentrates contain some other molybdenum-bearing mineral like molybdenite or powellite.

SILVER AND GOLD DEPOSITS

WINCHESTER DISTRICT

The northeastern corner of the Dragoon quadrangle is part of the Winchester silver district, which centers in Severin Canyon less than a mile north of the quadrangle boundary. The main part of the district was not studied during our survey. The following notes are based on a cursory field examination, information furnished by Mr. Burnie Gibbens (oral communication, 1952) of Dragoon, and a few references in Mineral Resources and the Minerals Yearbook.

Limestone of Paleozoic age that crops out in the district has been replaced here and there by lenses of jasperoid as much as 100 feet wide and 1,000 feet long. Shear zones in granite of Precambrian age have been silicified also. A little limonite is common in the silicified rocks, but no other metalliferous minerals were noted during our examination. Assays are said to show erratic concentrations of silver ranging from 1 to 40 ounces per ton, and a few small specimens are said to contain as much as 400 ounces per ton. The best values are said to be in yellow-stained jasperoid "that looks as though oil had been poured over it." The gold content is generally 0.05 of an ounce per ton or less. Only small parts of the jasperoid bodies have proved rich enough to mine.

Sometime during the 1890's, fairly extensive underground workings were opened in the largest jasperoid mass a short distance north of the Dragoon quadrangle, and some silver ore was shipped (Burnie Gibbens, oral communication, 1952). The production in subsequent years as given in Mineral Resources and the Minerals Yearbook (U.S. Bur. Mines, 1924–49) is as follows:

Year	Ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)
1924	200	"siliceous silver ore"			
1935	1	2.60	32	133	-------
1936	5	.4	173	22	65
1941	1	------	31	200	-------
1949	8	------	32	300	400

The production in 1924 probably came from the old dumps. The other shipments probably are from veins that cut the limestone in the northern part of the district. These veins carry base-metal sulfides; little relation between the content of base and precious metals is evident.

Replacement bodies of jasperoid make up about a quarter of the small outcrop of Paleozoic rock in the northeastern corner of the Dragoon quadrangle. The largest mass, about 100 feet wide and 700 feet long lies along the bounding fault on the north. Smaller masses commonly have a more northerly trend and an echelon pattern. The jasperoid resembles that farther north.

A few prospect pits have been dug, but the silver content is said to be very low.

YELLOWSTONE DISTRICT

An ill-defined area including the Johnny Lyon Hills has been called the Yellowstone mining district, after an old name for these hills. Local ranchers and miners recall reports of minor gold discoveries and shipments many years ago. The only published references to the district we have found are the following:

Mineral Resources, 1907, pt. 1, p. 164 (U.S. Geol. Survey): Several small shipments were made from different properties during the year, but the most important developments were carried on by the La Vantia Mining Co., which had an incline shaft 225 feet deep and about 800 feet of drifts. The property also has a 5-stamp mill equipped for amalgamation and concentration.

Mineral Resources, 1930, pt. 1, p. 1111 (U.S. Bur. Mines): A test sample of gold ore was shipped from the San Jose mine from Benson on the Southern Pacific Railroad.

It has not been possible to confirm these reports or even identify the properties referred to. The La Vantia Mining Co. workings could well be what is now called the American mine near the west edge of the Dragoon quadrangle three-quarters of a mile north of the Willcox-Cascabel road. There is no evidence that these workings were ever productive. Some ore is said to have come from what is known locally as Gold Mine ridge, a spur of the Johnny Lyon Hills extending westward in the granodiorite through the southern part of sec. 18, T. 15 S., R. 21 E.

Narrow veins containing traces of ore minerals cut the Johnny Lyon granodiorite and have been prospected at many places. A widely occurring type of vein is characterized by brown carbonate, opaline quartz, and limonite boxworks; these veins locally contain white calcite and traces of malachite, chrysocolla, and chalcocite. The veins are a few inches to 3 feet wide and apparently at most a few hundred feet long. They generally trend east to N. 75° E. and dip 25° to 50° S. They are probably of Tertiary age, for they cut lamprophyre dikes and also the thrust fault on the north side of Gold Mine ridge (fig. 25). About a mile north of Gold Mine ridge in the SE¼ sec. 12, T. 15 S., R. 20 E., veins of this type as much as 3 feet wide and 200 feet long have been explored extensively at 2 prospects. Small pieces of altered granodiorite and vein material showing considerable copper stain have been abandoned on the dumps.

Another vein type in the granodiorite consists of massive milky to opaline irregular quartz veins a few inches to 2 feet thick, which have a few vugs and open fractures lined with nearly clear quartz crystals. Traces of galena, chalcopyrite, pyrite, specularite, malachite, chalcocite, and limonite are visible, but the veins are very short and the ore minerals are not abundant. The veins generally trend N. 70° to 80° E. and dip steeply to the south. In the vicinity of Gold Mine ridge such veins are accompained by vertical northward-trending veins of the same composition. As these veins cut lamprophyre dikes they are also probably of Tertiary age.

The Johnny Lyon granodiorite contains local concentrations of specularite in an ill-defined band about a mile long and as much as 750 feet wide next to the large thrust faults north of the Willcox-Cascabel road. The granodiorite is here locally sheeted and contains thin veins of quartz and calcite striking about N. 25° E. and dipping 60° to 65° SE. The specularite, in plates as much as 2 cm in diameter, occurs in the quartz veins and also in veinlets and as a replacement of the ferromagnesian minerals in the granodiorite. In addition, the veins locally contain white calcite in pockets, brown vein carbonate, traces of pyrite, chalcopyrite, chalcocite, oxidized copper minerals, and, uncommonly, small pockets of white fluorite and tabular barite.

Numerous prospect pits and the American mine are located in this zone. At the mine an inclined shaft directed S. 68° E. at 55° is now flooded 90 feet below the collar, but the size of the dump indicates extensive workings. The last material deposited on the dump is quartzite and red-brown siltstone of the Pioneer shale indicating that the workings crossed a major fault structure. The dump material shows only traces of valuable ore minerals.

The formations of Paleozoic age in the thrust plates of the Johnny Lyon Hills contain traces of base-metal minerals at many places. On the peak south of Keith Ranch, scattered irregular fractures in the Escabrosa limestone contain thin veinlets of opaline silica which contains traces of pyrite, galena, and chalcopyrite. At the Tip Top No. 1 prospect which, is on the main ridge extending southeast from this peak, about 150 feet of irregular workings on two levels have been opened in the lower part of the Escabrosa limestone. The workings follow narrow porous breccia zones which generally trend northeast but ramify in all directions. These zones are generally 4 inches wide or less and contain fragments of dolomite in a matrix of coarse white calcite and quartz. Malachite, chrysocolla, limonite, and copper pitch are the principal ore minerals, but traces of primary chalcopyrite bornite, and pyrite are also visible. On a small bench near the portal, the owner, J. J. Wien of Benson, has stockpiled about a ton of low-grade oxidized copper ore.

There are numerous prospects in the overturned Devonian and Carboniferous section exposed on the west side of Tres Alamos Wash in sec. 22, T. 15 S., R.

21 E. The strongest mineralization was in the southern part of the area of outcrop where numerous steep vuggy milky quartz veinlets trending north to N. 5° E. cut the lower part of the Escabrosa limestone and the upper part of the Martin formation. Extensive silicification has taken place both in the basal dolomite of the Escabrosa and in the highest shale of the Martin. This silica is chalcedonic and white to brown, and dispersed throughout are malachite, chrysocolla, chalcocite, limonite, and considerable brown carbonate.

MINES AND PROSPECTS

JOHNSON CAMP COPPER-ZINC AREA

CORONADO COPPER AND ZINC CO. PROPERTIES

The Coronado Copper and Zinc Co., of Los Angeles, Calif., owns a large group of mining claims and fractions extending continuously from near the Hagerman and O.K. shafts northwestward to include the Republic, Copper Chief, Mammoth, Moore, Black Prince, Johnson Copper Development, Mackay, and Peabody workings (pl. 6). The property represents a consolidation of claims once of diverse ownership. The property is bounded on the southeast by the Keystone Mining Co. property.

MOORE MINE

The Moore mine, located a little less than a mile northwest of the Coronado Copper and Zinc Co. concentrator at Johnson, is the most recent development in the district. The first ore body, now known as the A ore body, was discovered in 1947 by diamond drilling from the surface. A new vertical shaft called the Moore shaft [12] was started about a year later and large-scale production got under way in 1951. Since the Republic mine was shut down in 1952, the Moore mine has been the only active mine in the district. Its total production by the end of 1954 had amounted to roughly 250,000 tons of ore averaging about 2½ percent copper and 6½ percent zinc. The mine was shut down in 1957 because of the fall in metal prices.

The Moore shaft is a vertical three-compartment shaft 800 feet deep. From it three levels have been driven, called the 400, 500, and 600 levels respectively (pl. 7). An inclined winze from the Mammoth mine connects with the 400 level.

The mine workings reveal complex block faulting that can be interpreted in several ways. The interpretation given on the section (pl. 7) and block diagram (fig. 31), is based on data available early in 1954 and involves the following sequence of faulting.

[12] Named for R. W. Moore, then general manager of the Johnson Camp unit of the Coronado Copper and Zinc Co. and later president of the company.

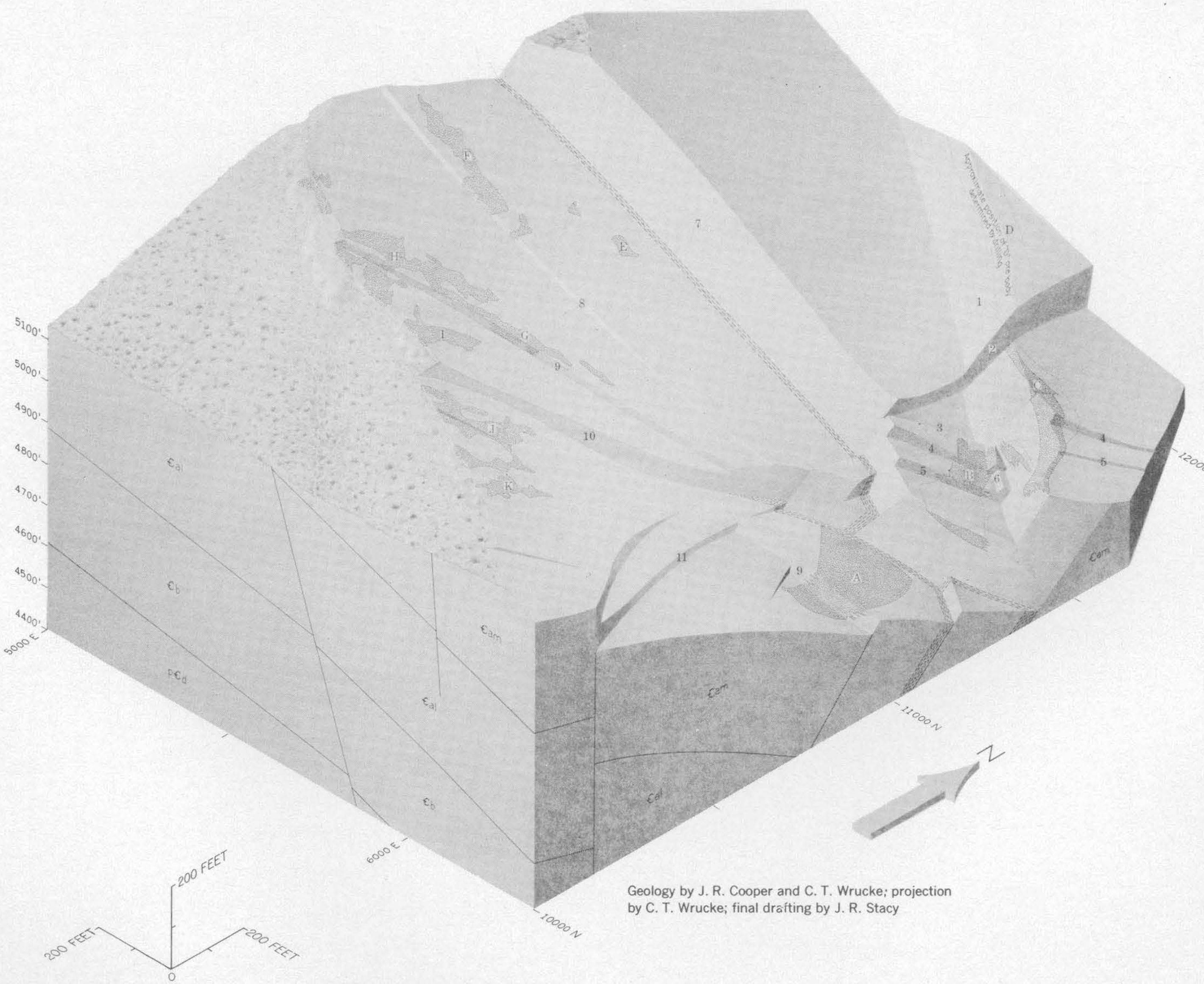
1. Fault A, a small normal fault of the Easter type, known only in a small part of the 500 level and not well understood.
2. Northeasters with small displacement of the normal type (including 467, No. 1 and No. 2 faults; and perhaps the 469 and No. 3 faults though the principal movement on them was later).
3. Easters with normal displacement (East 90 and Old Manto faults and perhaps the Mammoth fault though its principal movement was later).
4. Copper Chief fault, a Northwester with substantial right-lateral displacement. The No. 9 fault was formed as a segment of the Copper Chief fault at this stage.
5. Large normal movement on Mammoth fault offsets Copper Chief fault about 50 feet to the left.
6. Large normal movement on 469 fault offsets East 90, Mammoth and Copper Chief faults.
7. Renewed movement on Copper Chief fault, this time with relatively small downthrow on the west. As the old northern segment was now out of line, the movement at the north end took place on the No. 3 fault.

The metalization certainly followed stage 3 and was probably later, as the 469 fault contains veinlets of quartz and hypogene sulfides on the 500 level.

The principal ore bodies in the mine are chimneys or thick elongate lenses in the plane of the favorable beds (unit 5 of the Abrigo and the upper part of unit 4). Those mined or thoroughly explored to 1954 are 375 to 600 feet long, 50 to 175 feet wide parallel to the beds, and 30 to 70 feet thick perpendicular to the beds. The long axes are controlled by fault fissures or obscure northward-trending folds(?). Two of the ore boundaries tend to be plane surfaces parallel to the beds. The lateral boundaries, where not fissure-controlled, are irregular in detail because some beds were more easily replaced than others but the projections formed in this way are generally only a few feet long and the sides of the ore bodies are characteristically vertical or at some other large angle to the plane of the beds. To 1954 no important tabular extensions like those at the Republic mine had been found.

The A ore body is a lozenge-shaped mass 375 feet long, 175 feet wide, and as much as 60 or 70 feet thick plunging N. 10° W. in the favorable beds below the east end of the 400 level. It ends to the northwest against the 469 fault, though ore, now thoroughly oxidized, extends into the fault zone in one part of the 500 level (pl. 7). The structural feature that has localized the ore is very obscure. Baker (1953, p. 1275) believed it is a shallow fold.

The B ore body resembles the contracted extension of the A ore body offset 200 feet to the north by the 469



EXPLANATION

€am

€al

Abrigo formation (in part)
€al, lower member; €am, middle member; upper member and overlying formations removed in diagram

€b

Bolsa quartzite

CAMBRIAN

p€d

Dripping Spring quartzite

PRECAMBRIAN

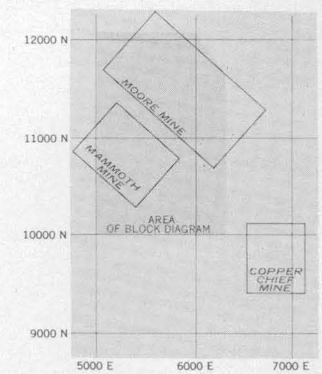
Ore body
Mined or known in 1953

Ore bodies:

A "A" ore body, Moore mine
B "B" ore body, Moore mine
C "C" ore body, Moore mine
D "D" ore body, Moore mine
E West Winze ore body, Mammoth mine
F Old Manto ore body, Mammoth mine
G 467 ore body, Mammoth mine
H No. 1 ore body, Mammoth mine
I No. 2 ore body, Mammoth mine
J Ore body, Copper Chief No. 3 mine
K Ore body, Copper Chief No. 2 mine

Faults:

1 East 90 fault
2 No. 9 fault (=Copper Chief)
3 No. 3 fault
4 No. 2 fault
5 No. 1 fault
6 "A" fault
7 Mammoth fault
8 Old Manto fault
9 467 fault
10 469 fault
11 Copper Chief fault



RELATION OF DIAGRAM AREA TO DETAILED MINE MAPS

FIGURE 31.—Block diagram of the Moore mine-Mammoth mine area showing relation of ore bodies to stratigraphic units and structure.

fault (pl. 7 and fig. 31). At the south end next to the fault the ore body is mostly above the 500 level. It plunges very gently to the northwest across the fault blocks defined by the No. 1 and No. 2 premineralization faults and ends against the E. 90 and No. 3 faults a little below the 500 level.

The C ore body is a nearly horizontal chimney in the favorable beds (Abrigo unit 5 and upper part of unit 4) between the 469 and No. 9 faults. The long axis of the chimney is controlled by the East 90 fault as shown in plate 7 and figure 31. Its diameter averages about 60 feet and only its downward bulges and undulations appear on the 500 level (pl. 7).

The D ore body is west of the No. 9 fault and about 100 feet above the 500 level. As known early in 1954, it appeared to be exactly like C in characteristics and geological controls (fig. 31). Late in 1954 after the illustrations for this report were prepared, ore was discovered in the same favorable beds immediately south of the East 90 fault in the block west of the No. 9 fault. The early drilling suggested it might be a chimney resembling the C and D ore bodies but structurally above rather than below the East 90 fault.

In addition to the principal ore bodies, some ore has been mined from a small mass at the top of unit 5 of the Abrigo intersected 100 feet southeast of the shaft on the 400 level (pl. 7), from a small body in white tactite cut by the shaft above the 400 level, and from a body in Martin unit 6 cut by drill hole No. 97 from the surface a short distance north of the main part of the workings (pl. 7). The ore in white tactite had a copper-zinc ratio near 1:1 and contained several percent of each metal. The body in the Martin formation is high-grade oxidized copper ore. As the discovery and development took place after our field work was completed, little information can be given concerning the mineralogical and structural details or the size of the mass. The ore is soft and porous. It contains much malachite and little gangue other than the original carbonate. Early shipments contained about 20 percent copper and very little zinc.

The ore bodies so far discovered in the mine and the unmined extension of the West Winze ore body of the Mammoth mine (p. 168) bottom considerably above the 600 level. There has been considerable unsuccessful exploration for relatively shallow ore south and southeast of the workings, and a limited amount of exploration for deeper ore to the north and northeast.

One of the most favorable targets for exploration is the faulted extension of the East 90 fault east of the 469 fault. To the end of 1954, its location had not been established. At that time, Arthur Baker 3d tentatively concluded that it was represented by the Easter shear zone that we designate Mammoth fault(?) in the stub crosscut east of the B ore body on the 500 level (pl. 7) and shown on the block diagram (fig. 31) downdip from the A ore body. Baker's interpretation is appealing if the B ore body is in fact the faulted extension of the A ore body as hinted previously to simplify description. (See fig. 31.) It faces geometric difficulties, however. The best match of the A and B ore bodies is obtained if the postore displacement on the 469 fault was 200 feet in a right-lateral sense without any vertical component of movement. All structures in existence at the time of faulting must have been offset the same amount and in the same direction. The offset of the contact of the garnetite and white tactite is in reasonably good agreement (185 ft on the 400 level; 220 ft on the 500 level); but the offset of the supposed East 90 fault on the 500 level is much too short (70 ft).

Even greater geometric difficulties are found with the other faults that we regard as older than the 469 fault. No right-lateral offset of the Copper Chief No. 9 fault system is apparent at the surface (pl. 6) or underground (fig. 31). If the Mammoth fault was offset 200 feet to the right it should pass through the A ore body. But mine workings and drill holes from the surface have shown conclusively that there is no Easter fault of consequence through the A ore body or updip from it.

It is possible, of course, that we have interpreted the fault sequence incorrectly. The Mammoth fault could be younger than the 469 fault but did not offset it appreciably because movement was parallel to the trace of the 469 surface. In this case the Mammoth could pass below the A ore body but not without crossing the 500 level. No fault that can reasonably be considered the Mammoth fault is to be seen on the 500 level west of the 469 fault.

On the basis of information available to us, we believe the 469 fault was not a strike-slip fault, but rather a normal fault which offset beds and Easter faults in opposite directions because of their opposite dips. According to this interpretation, the Mammoth fault is entirely above the 500 level workings west of the 469 fault; east of the 469 fault, the shear zone designated Mammoth fault(?) could represent part or all of the Mammoth fault. The faulted extension of the East 90 fault would be expected several hundred feet farther north in ground that had not been explored in 1954.

REPUBLIC MINE

The Republic mine is just east of the settlement of Johnson and is the site of the concentrating plant of the Coronado Copper and Zinc Co. The mine was opened in 1882 or earlier and worked at intervals until 1952 when it was shut down because of exhaustion of the known ore bodies. Total production was probably

550,000 tons of ore with a value somewhat in excess of $10 million.

Access to the mine is by an inclined shaft down the dip of the beds to the 700 level, about 400 feet vertically beneath the surface. Deeper workings are connected to the 700 level by winzes. The deepest level in 1954, the 1600 level, is 900 feet vertically beneath the surface. There is about 21,000 feet of drifts and crosscuts, in all, as well as raises, winzes, and stopes. The principal workings are shown on plate 8.

The geology of selected levels of the mine is shown on plate 9; and sections are given on plate 10. The beds strike near N. 50° W. and dip about 40° NE., and they are cut by many faults and fissures of the Northeaster and Easter sets. The Republic fault, a major flat-dipping Easter with normal movement, is exposed at the south end of the 1200 and 700 levels (pl. 9), in the shaft near the 600 level (pl. 10), and in the roof of the eastern part of the 700 Station stope (pl. 8). The workings driven from the shaft above the 700 level are entirely on the south or hanging-wall side of the Republic fault. The rest of the workings are on the north or footwall side of the fault except for several hundred feet of workings at the south end of the 1200 level and a short crosscut from the 700 Station stope.

Prior to our mapping, the Republic fault was not recognized, and the large ore bodies in the footwall block were thought to occur in the Martin formation, because of their position with respect to surface outcrops (pl. 10). As a result of the regional studies of the stratigraphy and metamorphism, it is now very clear that all the ore in the mine was in the middle member of the Abrigo formation, and most of it was in unit 5 at the top of that member. As a result of misconceptions regarding the stratigraphic position of the ore bodies and the structure, the favorable beds on the hanging-wall side of the Republic fault have never been thoroughly explored. Unit 5 on this side of the fault has the form of a wedge defined by its surface outcrop and the fault. The wedge has its apex 1,150 feet northwest of the shaft collar and widens to about 850 feet between the south end of the 1200 level and the surface.

Mining in the hanging-wall block of the Republic fault was all prior to 1912. Stopes, now caved, were opened east and west of the shaft above the 200 level, and another shallow ore body evidently was mined 850 feet northwest of the shaft, from a quarrylike opening about 100 feet across. The ore at the three localities was in garnetite derived from unit 5. The body just west of the shaft was a tabular mass in the plane of the beds along Northeaster zone H (pl. 9). This mass was 2 to perhaps 5 or 10 feet thick, about 150 feet long parallel to the trace of fault zone H, and 50 feet wide parallel to the strike of the beds. Details of the ore body east of the shaft are not now determinable but the body must have been considerably larger than shown on plate 8 for caving has caused appreciable subsidence of the land surface for several hundred feet from the shaft. There is no evidence of this ore body on the 300 level (pl. 9).

Since discovery of the Main Manto ore body, attention has been focused on the footwall block of the Republic fault. As the 500 and higher levels from the shaft are stratigraphically below the most favorable ore horizon west of fault G (pls. 9 and 10), the shaft and the segment of the 300 level that is southeast of the shaft provide the only exposures of the most favorable beds in the hanging-wall block between the stopes near the surface and the 1050 level. A horizontal hole drilled southwestward from the 1050 level penetrated the Republic fault and showed that unit 5 was barren and only slightly garnetized. Weak garnetization in unit 5 was also shown by limited exploration at the 1200 level and in 3 diamond-drill holes from the surface 200 to 800 feet farther east. The weak garnetization revealed by this deep exploration is in striking contrast with the intense garnetization in the shaft and on the 500 and higher levels. The contact of garnetite and marble is a favorable locus for metalization, and thus is a valid target for future exploration. Other specific targets in the block are provided by the intersection of Northeasters with the favorable beds. A small body of metalized ground was found at such an intersection at the south end of the 1200 level (pl. 9). The position of the intersection of large Northeasters with the favorable beds is shown on a structure contour map accompanying an earlier publication (Cooper, 1950, fig. 15). Experience has shown that the footwall side of metalizing fissures is most likely to be mineralized.

The large ore bodies on the north or footwall side of the Republic fault were not exposed at the surface. The Main Manto ore body, which was mined during World War I and which probably averaged a little more than 4 percent copper, had the form of a chimney plunging between 1° and 25° S. 60° to 85° E. (pl. 10). Excluding lateral extensions described later, the chimney was 1,500 feet long, 30 to about 100 feet wide in the plane of the beds, and 15 to 40 feet thick. Between the upper or northwest end, which is about 100 feet beneath the surface, and the 900 level, the manto was in the topmost beds of unit 5 of the Abrigo formation. Below the 900 level it cut gradually downward across the beds to the No. 1 fault. East of the No. 1 fault, which is a premineralization fault, the ore body turned toward the south and more abruptly downward across the beds as a sort of tail of little economic importance. Where it ended a short distance below the 1300 level it was in beds more than 100 feet stratigraphically below the top of the middle member. The 1300 level, named many years ago from its distance down the gently inclined East winze, is at a slightly higher elevation than the 1200 level named later from its distance down the Northeast winze. The ground on the eastward projection of the ore body has been explored thoroughly by diamond-drill holes from the 1300 level without finding any important extensions.

The long axis of the manto was approximately parallel to the Republic fault and 190 to 200 feet down the dip of the beds from it. Below the 700 level the manto followed the axis of a gentle anticlinal flexure in the beds. Above the 600 level there is no indication of the flexure and the localizing structure was probably obscure Easters satellitic to and somewhat steeper than the Republic fault. Such structures are illustrated by the 700 fault (pls. 9 and 10) and other Easters to be seen in the stopes at the upper end of the manto.

Above the 700 level, the Main Manto had several extensions in the plane of the beds. One of these, mined during World War I, ran updip between the No. 9 fault and the North Winze fault. The only downdip extensions known in this area are a thin hanging-wall streak which was mined here and there to the 700 level. Very little evidence of exploration for a possible footwall streak can be seen in this area.

East of the North Winze fault there was a downdip extension of considerably greater importance called the West ore body (pl. 8), which was also mined during World War I. This extension merged with the manto along a base 375 feet long and ended in depth as fingers following several Northeasters. In a stratigraphic sense, the extension split into a lower footwall streak and an upper hanging-wall streak, as well shown on the 700 level (pl. 9). Below the 600 level, the two streaks were mined separately. The longest finger of ore, a part of the footwall streak running down along the North Winze fault, was mined to about 25 feet below the 900 level. On the deeper projection of this finger, ore was mined in recent years above the 1200 level and between the 1200 and 1500 levels (760 ore body of pl. 8). This ore was in the same beds as on the upper levels, but the beds are here broken by large Easter faults of the reverse type. Baker (1953, p. 1276) believed this ore was localized along the axis of a shallow fold in the beds, but this fold is obscure and it seems just as likely that the structural control is a combination of the North Winze fault and the Easters.

For several hundred feet east of the West ore body, the Main Manto lacked extensions of any kind and was nearly circular in cross section. One thin downdip extension (hanging-wall streak), just west of the Northeast Winze, was mined to the 900 level.

Farther east, between the 700 and 900 levels, the manto expanded: and between the 900 and 1100 levels blossomed out into extensions of great importance. A large body of ore occurred in unit 4 just south of the manto, and a large tabular extension of this body called the Northeast Winze ore body occurred to the north in beds at the top of unit 5 (pls. 8 and 10). These extensions, which have yielded about half the total ore produced from the mine, were high in zinc (6 or 7 percent) and low in copper (about 2 percent) when compared with the Main Manto and most of the other ore bodies in the mine. A small chimney of high-copper ore within the Northeast Winze ore body along the No. 3 (Northeast Winze) fault was mined during World War I between the 900 and 1250 levels. The rest was mined by the Coronado Copper and Zinc Co. after 1942.

The Northeast Winze ore body, which has been mined to the 1600 level, was about 800 feet long in a N. 10° W. direction, 200 to 400 feet wide on the various levels, and 15 to 40 feet thick perpendicular to the beds. It appears to have been localized along the axis of a shallow anticlinal flexure in the beds, as Baker (1953, p. 1274) was first to point out. As shown on the geologic map (pl. 9) and on the Northeast Winze section (pl. 10) which crosses the ore body obliquely, it was at the same stratigraphic horizon throughout and was continuous except for separation caused by the 1280 Easter fault. It ended in depth between the 1500 and 1600 levels against the 1600 fault, an Easter with reverse stratigraphic throw of about 120 feet in the vicinity of the ore body (pls. 9 and 10). There was no evident reduction in the size of the ore body as the fault was approached. A possible extension on the north or footwall side of the 1600 fault has been sought by many drill holes put down from the 1400, 1500, and 1600 levels. Ore in minable grade and thickness was found, but no body could be blocked out that is large enough to justify the costly winze necessary to reach it. The structure of the block is complex and not well understood. If further exploration by drilling is undertaken at some future time, crosscuts to the northeast from the present workings should be driven to provide drill sites from which new information could be obtained. Only a small part of the footwall block can be explored satisfactorily by drilling from the present workings, and this part has been thoroughly explored.

Several hundred feet southwest of the Main Manto and in beds about 150 feet below it stratigraphically, there is a much smaller metalized chimney known as the West Manto. It follows a slight anticlinal flexure nearly parallel to the Main Manto. Not all the West

Manto is commercial ore. In 1920, or earlier, the 700 Station ore body was mined between the 500 and 650 levels (pl. 8). The Republic fault seems to cut off the ore body at its east end; but a low-grade stem, taken to mark the general course of the manto, continues downward on the footwall side of the Republic fault. This stem was found on the 700 level and led the miners to the ore body above. It is now evident that the stem continues downward at least to the 1200 level and contains other masses of ore. It has been explored by crosscuts on the 1050 and 1200 levels, by a raise from the 1050 level to the 700 level, and by several diamond-drill holes. The Coronado Copper and Zinc Co. opened the West Manto stope above the 1050 level (pl. 8) but later abandoned it because the ore proved to be thin and the ground bad for mining.

The principal ore bodies at the Republic mine were within the relatively uplifted block between the Republic and 1600 Easter faults. Without further exploration of the adjacent relatively depressed blocks, it is impossible to tell whether this is due to structural favorability of the uplifted block or simply to the fact that this block has been more thoroughly explored.

MAMMOTH MINE

The Mammoth mine is about three-quarters of a mile northwest of Johnson in a conspicuous hill known as Mammoth Hill. Its productive life started in 1882 or earlier and continued at intervals until 1949, when operations were suspended. Since the eighties, the Mammoth and Republic mines have had the same owners, and production from the two mines has been reported as a unit in most of the years for which there are records. Production from the Mammoth is very much less than from the Republic but probably exceeds that from the intervening Copper Chief mine. The Mammoth ore is similar to that from the other two mines but, on the average, is somewhat richer in copper.

The principal workings of the mine, shown on plate 7, consist of partly caved inclines and underhand stopes down the dip of the favorable beds and more extensive openings from the main inclined shaft that passes through the Old Manto stope to the 600 level. The favorable beds have been explored for a length of 650 feet on the 600 level and 2 stopes have been opened above it—a small stope near the west end and a larger stope near the east end. The eastern stope which is on the 467 ore body connects with an underhand stope from the surface. Below the 600 level there are two winzes corresponding in position to the two ore bodies on the level. A small ore body is partly developed and mined from the West winze. The East winze provides access to a stope at the bottom of the 467 ore body and extends to the Moore mine workings.

All ore bodies at the Mammoth mine are in unit 5 at the top of the middle member of the Abrigo formation. The No. 1, No. 2, and several smaller tabular ore bodies, 2 to perhaps 10 feet thick, cropped out at the surface and were mined many years ago by underhand methods (pl. 7 and fig. 31). The Old Manto ore body, mined during World War I, had only a small inconspicuous lead exposed at the surface, but good ore occurred 30 feet below. The body was a chimney about 300 feet long, 25 to 60 feet wide, and 10 to 25 feet high plunging gently eastward in the favorable beds on the footwall side of the Old Manto fault, a small Easter that may be traced on the surface as far east as the Moore shaft (pl. 6). The 467 ore body, mined during 1945–48, was a chimney 400 feet long, 25 to 45 feet wide, and nearly 25 feet high which ran almost down the dip of the favorable beds in the footwall of the 467 fault, a Northeaster. The body was discovered in depth and mined to within a very few feet of an old underhand stope from the surface—a good illustration of the fact that in districts of this kind one may be very close to good ore without realizing its presence. The 467 fault crosses the old stope obliquely and enters the east wall about a hundred feet down the incline. The fault has a subordinate branch at this point, running in a more northerly direction, and the early miners followed this branch downward.

The northern wall of the Old Manto stope shows 3 to 15 feet of low-grade zinc ore for a length of 250 feet. Lenses of similar ore downdip on the 600 level may represent the extension. A little of this ore was mined in both areas in the early 1940's by W. A. Hooton, a lessee, but the operations were not profitable. The stope later opened at the bottom of the West winze yielded good grade copper ore. The shape of the stope and diamond drilling from the surface and from the 400 level of the Moore mine suggest that the mined area represents the upper part of a small manto that plunges about 25° in a nearly easterly direction and extends about 400 feet from the bottom of the West winze. The ore is entirely above the 400 level from the Moore shaft, from which it would be most readily mined.

COPPER CHIEF MINE

The Copper Chief workings are about half a mile northwest of Johnson, between the Republic and Mammoth mines. The first mining was prior to 1900, but most was in 1905–19 by the Arizona Michigan Development Co. The mine has been closed since 1923, the date of merger of the Copper Chief and Republic-Mammoth properties. Production records extending back to 1903 indicate a production of 24,100 tons of ore averaging 4.2 percent copper and 0.5 ounces of silver per ton.

The principal workings, shown in figure 32, consist of the Copper Chief No. 1 inclined shaft which is 400 feet long, has about a thousand feet of drifts and crosscuts on several levels, and also raises and stopes. A vertical shaft, no longer accessible, was sunk several hundred feet northwest of (downdip from) these workings and a crosscut extended into the favorable beds 125 feet vertically below the bottom of the incline. Two other inclined shafts, known as the Copper Chief No. 2 and No. 3 inclines, are located 980 feet and 1,170 feet, respectively, northwest of the No. 1 incline. The stopes adjoining these shafts are shown on the block diagram of the Moore mine-Mammoth mine area (fig. 31).

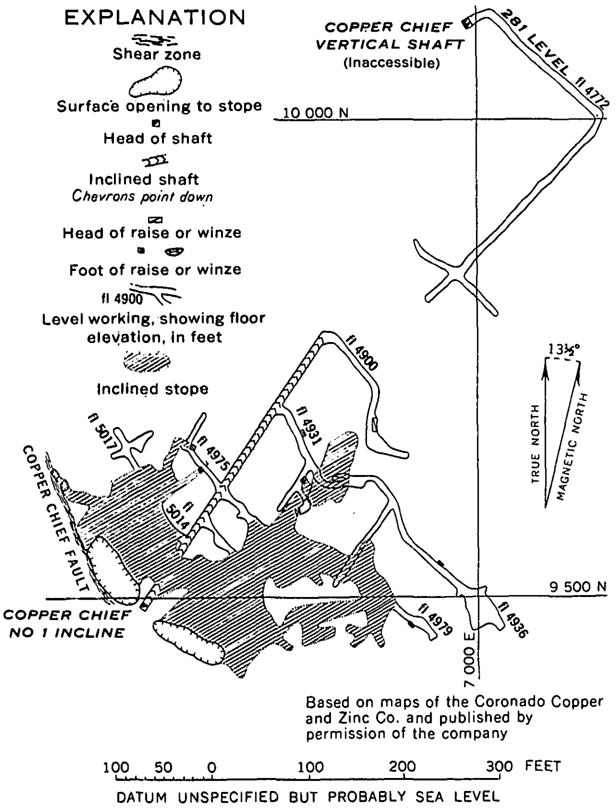


Figure 32.—Composite map of Copper Chief mine.

The Copper Chief ore bodies were tabular bedding replacements in the top 25 to 30 feet of the middle member of the Abrigo formation, which here dips 25° to 40° NE. The main ore body was exposed at the surface just east of the Copper Chief fault and was 230 feet long parallel to the strike of the beds and 5 to perhaps 20 feet thick. It ended in depth along an irregular line 100 to 325 feet down the dip of the beds. The ore was thickest and extended deepest near small Northeaster faults. The projection of the longest finger of ore is represented on the bottom level by a lens 6 inches thick. No ore was found in the vertical shaft workings though there is much slightly metalized garnetite on the dump. Diamond drilling north, east, and southeast of the vertical shaft has thus far failed to find ore.

The Northeasters are regarded as the mineralizing fissures but, for some reason, valuable deposits appear to have been formed only near the Copper Chief fault. Perhaps the Copper Chief fault was a dam for solutions rising along the intersection of Northeasters and favorable beds; or movement on the Copper Chief fault may have caused Northeasters near it to become open and permeable to ore-forming solutions. There is no evidence in the shape of the ore body to suggest that the Copper Chief fault was a channelway for the solutions.

Ore at the No. 2 and No. 3 inclines was in the same beds as at the No. 1 incline. (See fig. 31.) At the No. 2 incline, a lens roughly 6 by 60 by 140 feet in maximum dimensions has been mined. The long and intermediate axes are in the plane of the beds, and the long axis is nearly parallel to the dip. The lower part of the incline, which here cuts down gradually through the beds, and a short drift at its bottom have developed a small block of submarginal zinc ore containing some copper on the projection of the long axis of the ore body. From the No. 3 incline, about 3 feet of beds was mined, and no ore remains in the walls of the workings.

The ore produced from the three inclines is said to have been nearly all oxidized, consisting of malachite, chrysocolla, copper oxides, and native copper in a gangue of garnet and other lime silicates. The mineralized ground at the bottom of the No. 3 incline is unoxidized and consists of garnetite with some residual limestone and streaks of sphalerite and chalcopyrite.

PEABODY MINE

The Peabody mine is about a mile north of Johnson, at the north end of a low hill of Horquilla limestone. It was the first mine in the district to be extensively worked and is now nearly all caved. Therefore, information regarding the mine must come largely from descriptions of others. The following history has been pieced together from the files of the "Willcox Star" and from several other sources.

In 1882 the Russell Gold and Silver Mining Co., controlled by S. S. Campbell and other Philadelphia interests, owned the Peabody mine and started to smelt its ore in a small furnace about 2½ miles south of the mine, at what became known as Russellville, where a supply of water was available. The following year, a pipeline was laid from Russellville to the mine, and the smelter was moved there. That year, Hamilton (1883,

p. 87) wrote, "Regular bullion shipments are made, and the mine is thoroughly opened by shafts, drifts, levels, etc." Some time in the eighties, the mine was considered worked out; the smelter was removed, and the property was sold. The slag dumps resulting from this early operation indicate that perhaps 10,000 tons of ore were smelted. The value of the output has been estimated at more than $1 million (Dinsmore, 1909.).

From some time in the eighties until 1899, the property was owned by W. D. Hubbard of Hartford, Conn., who is said to have bought it for $10,000. Apparently the only mining in this period was by lessees, A. H. Wien and T. K. Mitchell, who made small shipments of high-grade ore in the late nineties.

In 1899 the Hubbard interests sold the property for $25,000 to the Dragoon Mining Co., organized by the Federal Copper Co., of New York with George Jaycocks, president, and H. J. Clifford, mine manager. The Dragoon Mining Co. started to mine vigorously. The ore was hauled to Cochise in wagons and shipped from there to the smelter in El Paso via the Southern Pacific Railroad. For nearly 3 years, a few contemporary press reports state that between 50 and nearly 200 Mexican miners were employed, and that ore shipments ranged from 3 cars per week to 2 cars per day. Production fell off in 1902, and in 1903 the company failed. The value of the production by the Dragoon Mining Company has been variously estimated between $250,000 and $1,000,000.

Between 1907 and 1918 the Peabody mine was worked by the Bonanza Belt Copper Co. and its successor, the Peabody Consolidated Copper Co. The recorded production was 14,200 tons of ore averaging 7.5 percent copper and 4 ounces of silver per ton. The mine has been closed since 1918, though lessees have shipped a few hundred tons of ore, sorted from the dumps.

The Peabody mine is in the Horquilla limestone, which, in the vicinity of the mine, is recrystallized and has thin bands of garnet, idocrase, wollastonite, and other lime-silicate minerals. Chalcopyrite, bornite, and sphalerite—or more commonly their oxidation products—occur in the silicated layers and along crosscutting fissures. A host of prospect pits and opencuts are scattered over the hill slope; the main workings are at the north end of the outcrop area and extend out under the alluvial cover. In the small part of these workings that was accessible in 1945 (fig. 33), tabular ore bodies were mined in the plane of the beds and in the plane of a typical Easter. A few Northwesters are known but typical Northeasters seem to be wholly lacking. According to Scott (1916, p. 141), the ore "occurs in a contact vein between lime and diabase and in several replacement veins all within a 100-foot belt." The "diabase" is almost certainly the lamprophyre of our report, as shown by fragments on the dumps.

According to Scott (1916, p. 141), the ore at the Peabody mine was oxidized to a depth of 200 feet—which is probably about the maximum depth reached. The ore mined in the eighties was very rich in copper and silver, according to local residents and according to Dinsmore (1909) who stated that it was rarely below 15 percent copper and that many carloads ran 40 to 45 percent. The ore produced after 1906 averaged 7.5 percent copper and 4 ounces of silver per ton.

We found no reference to the occurrence of zinc in the mine but did find a few pieces of high-grade sulfide and oxide zinc ore on the dump. As oxidized zinc minerals are difficult to recognize in the field, dry bone ore might have been overlooked. Therefore, we collected four grab samples which were analyzed by the Coronado Copper and Zinc Co. with the following results:

Description of specimen	*Cu*	*Pb* (*percent*)	*Zn*
1. Oxidized zinc ore, rusty, porous, visible hemimorphite, a little aurichalcite, and malachite	2. 95	3. 5	44. 2
2. Many seams of silica and carbonate, weathered surface porous resembling bone	. 38	3. 2	. 5
3. Porous, cut by white and reddish gray carbonate veins	. 25	2. 6	. 3
4. Rusty, seams of white and pale-green carbonate	. 23	2. 9	. 2

The zinc content of the last three samples was disappointingly low. The appreciable lead content was surprising as this metal is nearly lacking from the replacement sulfide ores of the district so far as known.

BLACK PRINCE WORKINGS

Mine workings on 8 patented mining claims west of the Peabody mine, and ½ to 1 mile north of Johnson, are known as the Black Prince workings because the work was done by the Black Prince Copper Co. (1901–11). The principal opening is the Black Prince vertical shaft, said to be nearly a thousand feet deep; a crosscut was driven toward the southwest on the 900 level. The shaft was inaccessible at the time of our fieldwork but was reconditioned by the Coronado Copper and Zinc Co. in 1957 to get drill sites for deep exploration. No ore was found in the shaft or the crosscut. The shaft is entirely in the Horquilla, Black Prince, and Escabrosa limestones; but units 5, 6, and 7 of the Martin formation were reached in the crosscut (Richard Bergman, oral communication, 1957). The favorable beds of the Abrigo formation were tested by drilling from the crosscut, but, to our knowledge, no ore was found.

In addition to the shaft there are numerous pits,

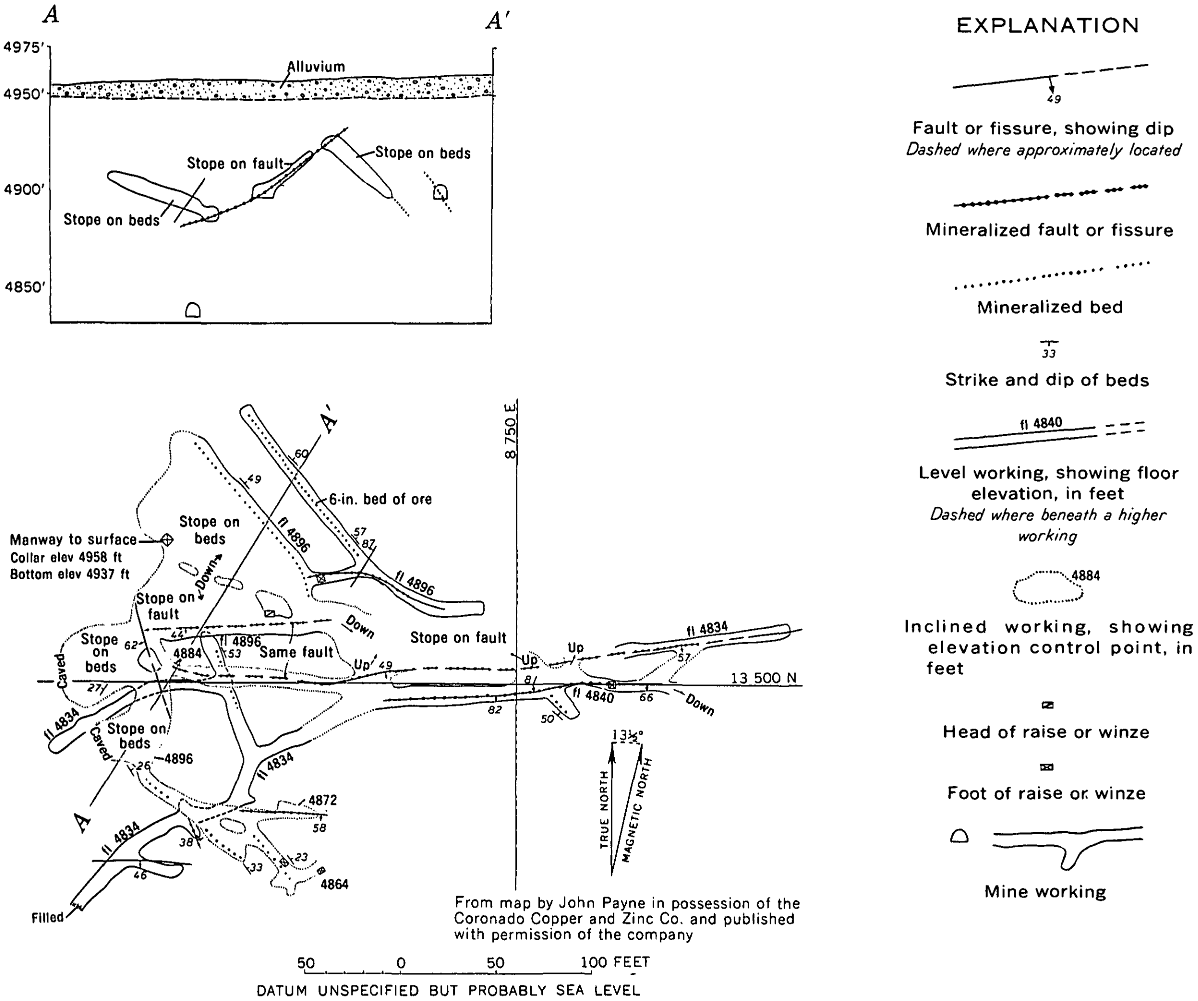


FIGURE 33.—Composite geologic map and cross section of the accessible part of the Peabody mine.

several small underhand stopes from the surface, and the Copper Bell adit which is 1,100 feet south-southeast of the shaft. The only production recorded is 1,400 tons of ore, which averaged 8.6 percent copper and 5 ounces of silver per ton, and which was shipped from the Copper Bell adit and nearby surface workings in 1902–18.

All the limestone of Carboniferous age exposed at the surface contains traces of copper minerals and a few stringers rich in quartz and bornite. Commercial ore appears to be confined to thin layers in the Horquilla limestone and to concentrations along fault fissures. These occurrences are illustrated at the Copper Bell adit, shown in figure 34. Oxidized ore was here mined along a typical Northeaster and, to a more limited extent, from a thin band of garnetite in the Horquilla limestone. The sulfides bornite, chalcopyrite, and sphalerite occur in the garnetite on the adit level. Sulfide ore appears to have been of no interest to the miners for the garnetite band was not explored on the adit level, even though it carries appreciable quantities of sulfides, particularly bornite, at the two places exposed. The small fold, to be seen on the surface and used as a basis for the interpretation of underground map and cross sections, is an uncommon type of structural feature in the Johnson district.

MACKAY GROUP

Several claims between the Peabody mine and the Climax (Johnson Copper Development) shaft are known as the Mackay group. During 1900 and 1901, the "Willcox Star" reported shipments of rich copper ore from this property, first by Melzer Osborn and Sam Bigler, and later by Col. H. C. Hooker and associates, who purchased the property in 1900. The production came from the Magazine and Peoples Party claims that adjoin the Peabody claim on the southwest and southeast respectively. In 1906 and 1907 the Magazine Copper Co. shipped 454 tons of ore, which averaged 7.3 percent copper and 3.1 oz per ton silver and was reportedly from the Peoples Party claim. No record of later production has been found.

The bedrock is the Horquilla limestone, which ap-

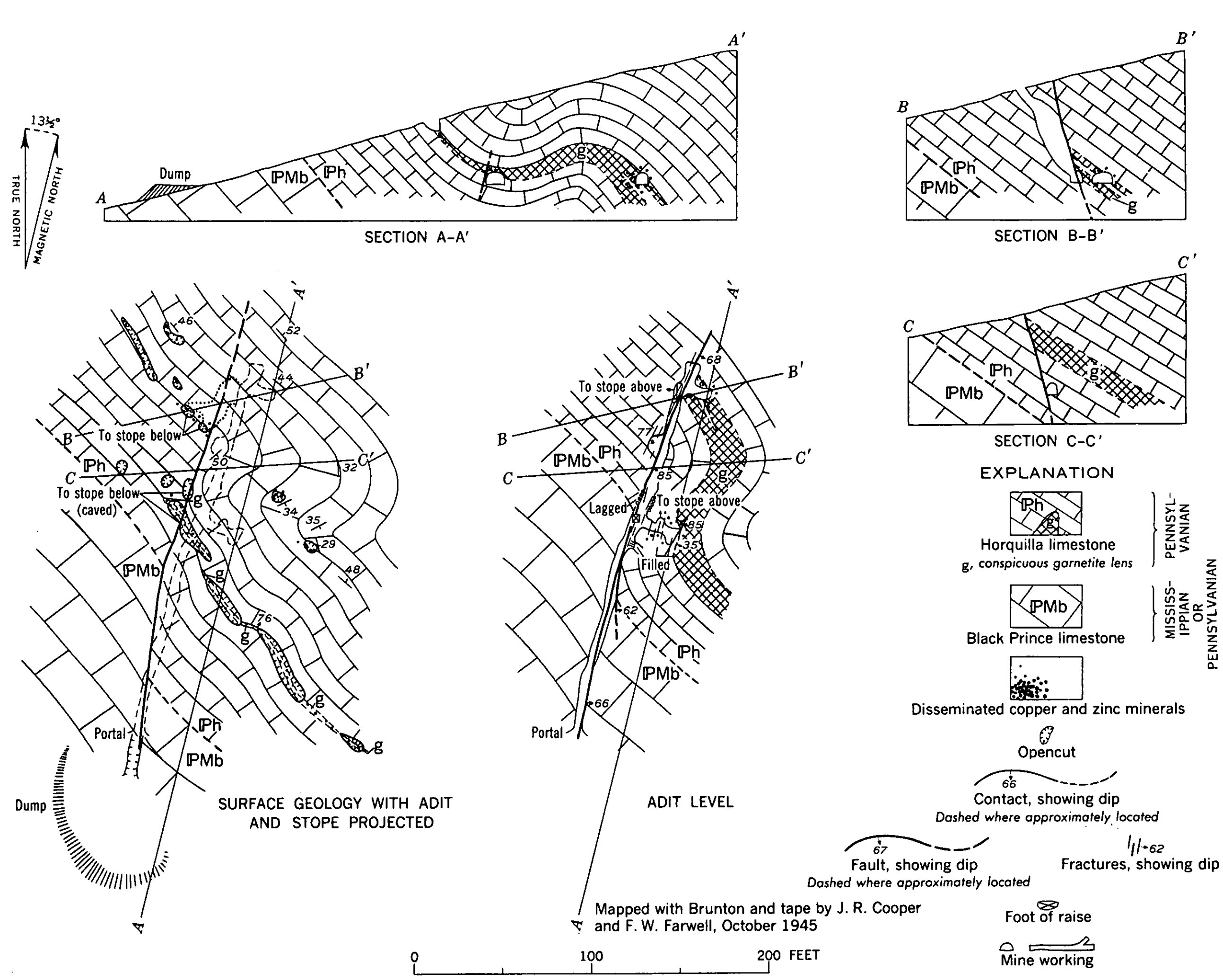


FIGURE 34.—Geologic maps and sections of the Black Prince (Copper Bell) adit.

pears to be mineralized in the same way as in the nearby Peabody, Black Prince, and Johnson Copper Development workings. Ore minerals—principally bornite, chalcopyrite, and their oxidized equivalents—are concentrated locally in silicated beds, which are generally less than 5 feet thick and which are separated by much thicker beds of barren limestone. The most extensive workings are on the Peoples Party claim and consist of a vertical shaft now inaccessible and many pits and small underhand stopes. These workings are on the faulted extension of the beds that are mineralized on the Peabody claim. The ore on the Magazine claim came from a shallow incline and surface workings.

JOHNSON COPPER DEVELOPMENT (CLIMAX) SHAFT

The Johnson Copper Development shaft is on the Climax claim, which is just southwest of the old Mackay group and southeast of the Black Prince group (pl. 6). The shaft, said to be more than 700 feet deep, was sunk between 1908 and 1916(?) by the Johnson Copper Development Co. A little additional work by this company was done at intervals through 1930. The shaft has not been maintained in recent years and is no longer accessible. Little if any ore came from it, for the total recorded production of the Johnson Copper Development Co. was half a dozen small shipments between 1912 and 1930, totaling only 207 tons of ore. Some of this ore came from open pits on the property. The grade (average 9.9 percent copper, 5.2 ounces per ton silver) was good and similar to that of the ore from the nearby Peabody, Black Prince, and Mackay workings.

Local miners report that the upper part of the Climax shaft is vertical and the lower part inclined. According to Scott (1916, p. 141), it is vertical to a depth of 250 feet where there is a 500-foot drift and a 500-foot winze. The collar is in the Horquilla limestone, and the dump suggests that the workings are entirely within the formations of Carboniferous age. Copper carbonates were found near the surface, and bornite has been reported at depth (Dinsmore, 1909, p. 834; Scott, 1916, p. 142).

OTHER PRODUCTIVE WORKINGS

The Coronado Copper and Zinc Co. property includes the outcrop of the favorable beds in the Abrigo formation between the Republic mine and the Keystone fault. Part of the early production from the district came from opencuts and shallow inclines in this area. Ore was mined from several zones in the middle member of the Abrigo formation. The largest and presumably most productive workings (no longer accessible) are on the Chicora and Southern claims, which were patented in 1882 and have belonged to the owners of the Republic mine since that date. The Mayflower claim, which adjoins the Chicora on the north and the Republic on the east, was worked early in this century by a local company called the Mayflower Mining Co. with George Parsons, manager. Two carloads of ore averaging 5½ percent copper were shipped late in 1907 from a short incline below the outcrop. Soon thereafter a vertical shaft, called the Mayflower shaft, was sunk to intersect the mineralized beds several hundred feet below the surface. There is no record of ore shipments from the shaft. The size and composition of the dump indicate that underground workings are not extensive though the middle member of the Abrigo formation evidently was reached.

In 1905, 50 tons of ore averaging 12½ percent copper was shipped from an opencut on the Copper King claim 300 yards north of the Republic shaft. The ore occurred in the Escabrosa limestone along a small and relatively steep Easter, a short distance south of the Republic fault. The ore pocket appears to have been completely mined out. Its importance is in suggesting that ore bodies of importance may occur if similar structural conditions are duplicated in depth where the favorable beds of the Abrigo formation make up the hanging wall of the Republic fault.

KEYSTONE COPPER MINING CO. PROPERTY

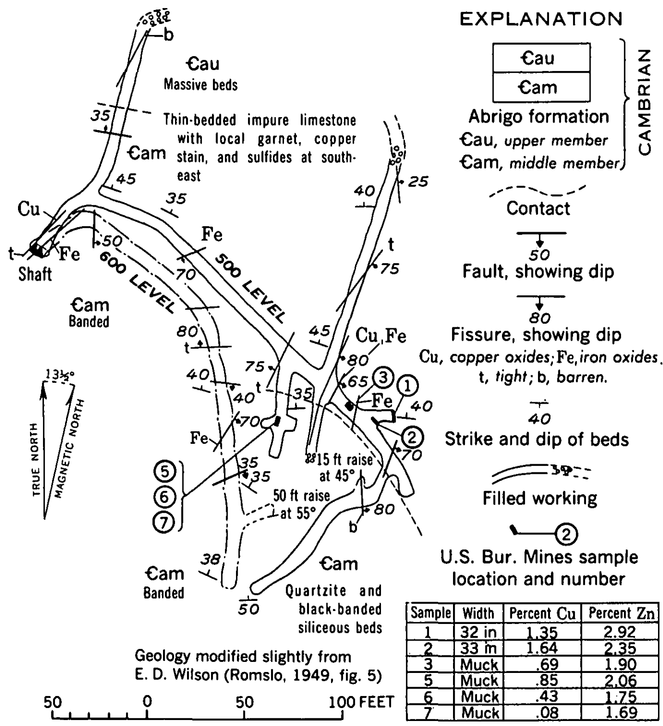
The Keystone Copper Mining Co. of Dragoon (N. M. Rehg, president and general manager; executive office El Dorado, Kans.) owns 50 unpatented claims and fractions, southeast of the Coronado Copper and Zinc Co. property. The Keystone property includes a small block of ground just west of the Keystone fault and most of the outcrop of the Paleozoic formations east of that fault. Development consists of many pits and shafts, the deepest of which are the Keystone (Hagerman) and O.K. shafts. A 200-ton flotation concentrator was completed near the Keystone shaft in 1925 and was operated for a brief period. Most active mining was during World War I, and the last shipments were in 1937. Records for the period 1916–37 show a total production of 1,853 tons of ore averaging 4½ percent copper. This ore came from the O.K. and Keystone shafts and from other workings.

In 1947 and 1948 the U.S. Bureau of Mines drilled 20 exploratory diamond-drill holes near the Keystone shaft and 2 holes near the O.K. shaft. Nine of the holes near the Keystone shaft were on the St. George claim, which was owned by F. M. Lebold and S. N. Lebold of Chicago rather than by the Keystone Copper Mining Co. The detailed results of the work have been published by the Bureau of Mines (Romslo, 1949). In the following pages, the results are discussed in more general terms in connection with the mine involved.

KEYSTONE (HAGERMAN) MINE

The Keystone or Hagerman mine is a mile southeast of Johnson near the Dragoon road. Access is by a vertical shaft reported to be 680 feet deep. Levels known as the 60, 200, 300, 500, and 600 are 60, 200, 325, 487, and 565 feet, respectively, below the collar. In 1945 water was standing in the shaft about 3 feet below the 600 level. We did not examine the underground workings because ladders had been removed from the shaft and the hoist was not operating at the time of our work in the vicinity. The mine map (fig. 35) is taken from the report by Romslo (1949, fig. 5) and shows geology of the deeper levels as mapped in 1945 by E. D. Wilson of the Arizona Bureau of Mines. Surface geology and sections are shown on plate 11.

Ore produced from the Hagerman workings is said to have come largely from the upper levels, presum-



Sample	Width	Percent Cu	Percent Zn
1	32 in	1.35	2.92
2	33 in	1.64	2.35
3	Muck	.69	1.90
5	Muck	.85	2.06
6	Muck	.43	1.75
7	Muck	.08	1.69

FIGURE 35.—Geology of the 500 and 600 levels from Keystone (Hagerman) shaft.

ably from the Escabrosa and Martin formations. No maps or other data are available for these levels, which were not readily accessible in 1945. The 500 and 600 levels are in the Abrigo formation. At the east end of the 500 level, the middle member is partly garnetized and, at one place, about 3 feet of beds are weakly mineralized with copper and zinc sulfides (fig. 35).

Bureau of Mines drill hole 1 confirmed the extension of this mineralized zone about 20 feet southeast of the showing on the 500 level as shown on section *B–B′* (pl. 11). Drill holes farther southeast failed to reveal its presence but indicate two other loci of low-grade sulfide mineralization, as shown on section *A–A′* (pl. 11). Along the line of section *A–A′*, for a distance in excess of 160 feet, parts of unit 5 of the Martin, 2 to 13 feet thick, contain 0.6 to 1.2 percent copper but little other metal. The Abrigo formation is mineralized somewhat sporadically in the vicinity of a fault inferred from the absence of beds in the drill holes. This fault, which was not observed at the surface, has a calculated strike of N. 63° E., a dip of 36° SE., and normal displacement. It is classified as an Easter and regarded as premineralization. The Abrigo formation near it contains local concentrations of chalcopyrite and sphalerite and also concentrations of molybdenite. The best molybdenite showings are in the upper member and include 0.9 of a foot of 4.1 percent molybdenum in hole 23 and 7.3 feet of 1.02 percent molybdenum in hole 22. Complete assay data for all the holes are given by Romslo (1949, p. 18–21). The metal occurrences are of interest chiefly in clarifying the geologic factors that localized the metals and in providing leads in the search for commercial ore bodies.

O.K. MINE

The O.K. mine is near the northwestern boundary of the Keystone property and 1,800 feet southeast of the Republic shaft. Development consists of an inclined shaft, which is reported to be 450 feet long, and some short level workings and small stopes (fig. 36). In 1945 water was standing in the shaft at an elevation of 4,723 feet, 385 feet on the incline and 223 feet vertically below the collar. Several carloads of ore were shipped from the mine prior to 1920 ("Willcox Star," Apr. 30, 1920).

The shaft is at the very top of the Abrigo formation and is parallel to the dip of the beds, which strike about N. 30° W. and dip 30° to 35° NE. The basal beds of the Martin formation are exposed at places in the workings. Small faults and fissures strike N. 30° to 70° W. Near the surface the quartzite unit at the top of the Abrigo formation contains seams and pockets of iron oxide and oxidized copper minerals, mostly chrysocolla. A small ore body in this unit was mined just north of the shaft, as indicated on the mine map (fig. 36). The ore body was about 6 feet thick, judging from ore remaining in the stope walls and pillars.

At a depth of 330 feet along the incline, the shaft intersected a steep northwestward-striking vein, 1 to 4 inches thick, of chalcopyrite, sphalerite, and pyrite associated with quartz and oxidized ore minerals. This vein has been explored by a drift 150 feet long and a winze 10 feet deep. A little stoping has been done along the vein.

To test the possibility that the known deposits might represent leaks from a larger body in more favorable beds below, the U.S. Bureau of Mines drilled two diamond-drill holes at the points indicated on the map. A few bands that contain scarce chalcopyrite were found in the upper member of the Abrigo formation in both holes but the middle member was unmineralized. Assay data and abbreviated geologic logs of the holes are given by Romslo (1949).

ST. GEORGE CLAIM

The St. George patented mining claim, just south of the Keystone (Hagerman) shaft, was worked prior to 1890 and was intermittently worked to the early years of this century. It was owned in 1955 by F. M. Lebold and S. N. Lebold, of Chicago. The principal development is in the Martin formation and consists of an open pit from which several inclines—now inaccessible—descend parallel to the dip of the beds. According to the "Willcox Star" of July 3, 1903, 25 carloads of ore averaging 7.5 percent copper had been shipped prior to that date. There is no indication of subsequent production.

The surface geology and sections of the claim are shown on plate 11. The ore mined occurred at the top of unit 1 of the Martin formation and, judging from remnants in the cut and on the dump, appears to have been thoroughly oxidized. Perhaps 2 to 5 feet of beds was mined, but little of the remaining material appears to be of ore grade. Drill holes reveal only scarce traces of metalization at this horizon (pl. 11).

Diamond-drill holes a short distance northeast of the open pit revealed a zone of disseminated ore minerals in the middle member of the Abrigo formation (section *C–C′*, pl. 11). The mineralized beds are lower stratigraphically than the large ore bodies of the district but are about at the horizon of the West Manto ore body of the Republic mine and shallow ore bodies on the Chicora and Southern claims. The ore minerals are chalcopyrite, sphalerite, bornite, and scarce scheelite and molybdenite. The gangue is largely garnet and other lime silicates. Only thin streaks are of ore grade.

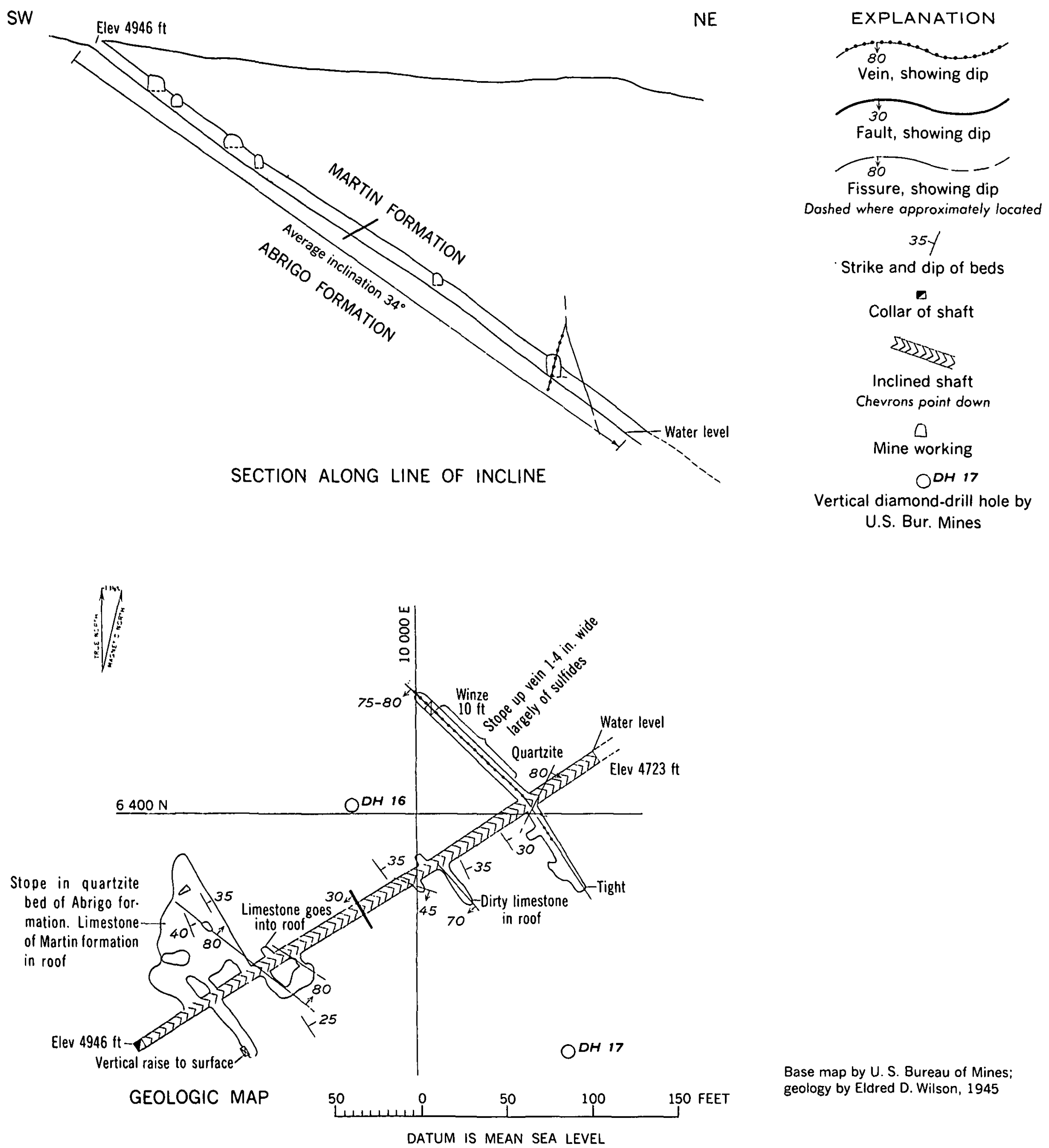


FIGURE 36.—Geologic map and section of the O.K. mine.

The richest concentration is in drill hole 5, in which one 5-foot interval averaged 2.2 percent copper, 2.2 percent zinc; and another 15.8-foot interval averaged 1.9 percent copper, 3.6 percent zinc. In adjacent drill holes 10, 11, and 12, the thicker interval is represented by 12.7 to 18.5 feet ranging in grade from 0.9 to 1.3 percent copper and 0.6 to 1.8 percent zinc. Detailed assay data and abbreviated logs of the holes are given by Romslo (1949).

Parts of the middle and upper members of the Abrigo formation are missing in all the drill holes on the St. George claim. To explain the absence of beds, we have inferred a preore fault that is approximately parallel to the bedding, as shown on the sections (pl. 11). This fault has not been recognized at the surface but could explain the peculiar and unexplained narrowing toward the west, of upper units of the Abrigo and the Martin as shown on the geologic map (pl. 11). Drill holes 7, 8, and 9 in the western part of the claim indicate complex faulting that cuts out hundreds of feet of beds, as shown in section *C–C′* (pl. 11). This could be due to faults similar to the one inferred farther east or to the Keystone fault, which trends northeast and has a throw of about a thousand feet. The former interpretation is shown tentatively on the section because the trace of the Keystone fault on the topography indicates a steep dip.

PROSPECTS NEAR JOHNSON

There has been considerable prospecting in the vicinity of Johnson beyond the limits of the properties so far described, both beneath the alluvial cover to the east and in the bedrock exposures to the west and south. Although traces of ore minerals have been discovered in every formation down to and including the Pinal schist, no ore has been produced so far as known and no promising signs for disseminated deposits of importance have been uncovered. Some notes concerning a few of the more extensive workings follow.

PITTSBURG (COCHISE DEVELOPMENT CO.) SHAFT

The Pittsburg shaft, 1,850 feet east-southeast of the Peabody shaft, was sunk in 1907 by the Cochise Development Co. The shaft is vertical and said to be 600 feet deep. A crosscut on the 500 level is reported. The collar is in alluvium but limestone and hornfels of the Horquilla limestone were reached. No ore was produced but the dump shows traces of copper minerals. Work ceased about 1910 but the Pittsburg claim and the Treasure claim which adjoins it on the northwest were patented in 1917 and were owned in 1955 by Mrs. Thomas Adams of Dragoon.

LIME MOUNTAIN WORKINGS

The Lime Mountain workings consist of several adits totaling about 1,200 feet in length on the east flank of Johnson Peak 1½ miles northwest of Johnson. The earliest work in the area appears to have been by the Lime Mountain Copper Co., formed in 1907, but much of the work was done by Mr. Pete Dworshek of Johnson who later held the claims. The adits explore parts of the Martin formation and the upper member of the Abrigo formation in the vicinity of northward-trending faults. The formations are not metamorphosed. Traces of oxidized copper minerals are to be seen here and there in the sheared and locally silicified rock that marks the faults. No ore has been produced.

EMPIRE WORKINGS

The Empire Gold and Copper Mining Co., formed by Los Angeles and Arizona interests with J. L. Brooks as president and general manager, did much exploratory work west of Johnson in 1905–09. No ore was produced. The first work was in the form of 3 adits which are on the south slope of Johnson Peak, 1½ miles west of Johnson. There are in all about a thousand feet of drifts and crosscuts and a connecting raise roughly 150 feet long. The upper part of the Bolsa quartzite and the lower part of the Abrigo formation are explored. The rocks are virtually unmetamorphosed and the only ore minerals noted are weak copper stains along joints and small shear surfaces.

In addition to the adit work, a vertical shaft known as the Empire No. 1 shaft was sunk in the Pinal schist 1 mile west of Johnson. The shaft, which is now completely filled with surface wash, is said to have been 400 feet deep. A 150-foot crosscut at a depth of 225 feet is reported. The workings are in the slightly broken ground between two northward-trending faults. Some copper stains are to be found along cracks.

In 1909 the company purchased the O. T. Smith property, 1½ miles southwest of Dragoon, and soon thereafter the operations near Johnson were abandoned. The Empire No. 2 vertical shaft, said to be 300 feet deep, was sunk on the property west of Dragoon. (See pl. 1.) The shaft is in the Horquilla limestone, which is partly silicated and cut by small quartz veins that contain bornite, chalcopyrite, and locally galena and scheelite. Shipments of 60 tons of ore averaging 11 percent copper and 4 ounces of silver per ton are reported for the period 1909 to 1913. The property later reverted to O. T. Smith and in 1947 was held by Lynn Burrell of Dragoon. In 1946 or 1947 Bruce Gilbert made a small shipment from an opencut on a narrow quartz vein just south of the shaft.

DRAGOON COPPER AREA

CENTURION MINE

The Centurion mine is near the contact of the Texas Canyon quartz monzonite stock about 4 miles south of Johnson and 2 miles north of Dragoon. The workings consist of an inclined two-compartment shaft 630 feet deep from which 7 levels have been driven (pl. 12). The work was done in 1908–11 by the Centurion Arizona Mining Co., J. P. Richardson, president. The mine was last operated in 1943 and 1944 by the Captain Mining Co. and was owned in 1955 by Mrs. S. J. Landfair of Dragoon. Total recorded production has been approximately 1,500 tons of crude ore averaging 4.3 percent copper. Very small amounts of silver and gold occur in the ore.

The mine has explored a part of the Centurion fault which strikes about N. 68° W., dips about 74° SW., and brings the Escabrosa and Black Prince limestones on the southwest against Pinal schist on the northeast. The principal movement on the fault took place before intrusion of the quartz monzonite which is not displaced by the fault but is intrusive along it as a tongue that reaches almost to the Centurion mine (pl. 1). The fault was reactivated and minor adjustments took place after intrusion of the quartz monzonite and associated aplite. The mineralization occurred during this later period of faulting for the igneous rock is sheared and silicified along the fault line, and contains ore minerals. As exposed at the surface the vein consists of 5 to 10 feet of much silicified rock containing oxidized iron and copper minerals and traces of chalcocite, all considered supergene. The vein material is brecciated and re-cemented at places. The overall copper content is very low.

The vein is also exposed on the 300, 400, 600, and 700 levels of the mine where it is represented by as much as 25 feet of sheared and altered rock containing much iron oxide and local concentrations of copper. A little ore has been obtained from sheared and altered limestone in the hanging-wall part of the vein, but no extensive ore bodies have been found. Part of the mine's production has come from small concentrations along minor faults and fissures, the detritus in natural solution caves, and locally mineralized beds in the limestone as much as 100 feet southwest of the main vein.

The ore is oxidized to the deepest level and consists of malachite, chrysocolla, and copper oxides in a gangue of sheared and brecciated marble, fault gouge, vein quartz, chalcedony, calcite, and in places garnet and other lime-silicate minerals. Native copper has been reported but was not seen during our mapping. Caves found on the 300 and lower levels are partly filled with marble fragments and limonitic debris in places coated with velvety malachite.

Both copper and iron have evidently been moved by supergene processes and the nature of their primary occurrence is not known. The shaft bottomed at the water table, according to contemporary newspaper accounts. At the time of our mapping, water was standing in the shaft—and also in a shallow winze—a foot or two below the 700 or lowest level. This suggests a stable water table and hence the possibility that unoxidized material may occur not far below. The abundance of limonite in the mine might be interpreted as a favorable sign for a zone of supergene copper sulfide enrichment in the unoxidized zone. The supergene waters that dissolve copper are acidic, and these solutions are quickly neutralized in contact with calcite, depositing the copper as carbonate or other compound. Thus in a calcite-rich environment like the Centurion mine, copper is not carried far and a zone of secondary sulfide enrichment is not to be expected.

PROSPECTS SOUTHWEST OF THE CENTURION MINE

The Paleozoic formations that border the Texas Canyon quartz monzonite stock southwest of the Centurion mine have been explored for copper by hundreds of pits and shafts, most of which were sunk prior to World War I by J. B. Gregory, Jim Neal, C. F. Elliot, Thomas Higgins, H. J. Clifford and O. T. Smith, the Empire Copper and Gold Mining Co., and others. A very few small ore shipments have been made but none of the workings can be regarded as other than a prospect.

The carbonate rocks of the area are locally silicated and contain small and generally low-grade concentrations of oxidized copper minerals and in a few places scheelite. John Walker (oral communication, 1950) informed us that O. T. Smith shipped 27 tons of high-silver ore of this type from the exposure of the Horquilla limestone south of the Southern Pacific tracks 1¼ miles southwest of Dragoon; and John Walker shipped 20 tons of copper-silver ore from an opencut in the same formation near the quartz monzonite contact about a mile southeast of the old Texas Canyon schoolhouse. This production indicates the small size of the ore bodies that have been found.

Much of the exploration in the area has been on small quartz veins that contain pyrite, chalcopyrite, bornite, galena, and locally scheelite. Small shipments of copper ore from these veins have been made but the deposits have proved too small for profitable mining. A few hundred pounds of tungsten concentrates has also been produced from the veins.

LEGAL TENDER PROSPECT

The Legal Tender mining claim, patented by the late O. T. Smith and associates in 1916 and owned in 1955 by Mrs. Thomas Adams of Dragoon, lies in the broad valley east of the Little Dragoon Mountains about 2½ miles southeast of Johnson and 2 miles northeast of the Centurion mine (pl. 1). This claim is on the only outcrop of Paleozoic rock between the Centurion mine and a point near the Keystone mine. The outcrop, shown in figure 37, consists of bands of tactite and recrystallized limestone which strike about N. 20° W. and dip 34° to 61° NE. The principal working is an inclined shaft, about 150 feet deep, down the dip of a limestone band. The rock in this shaft and in a number of shallower workings contains seams and small pockets of oxidized copper minerals, mostly chrysocolla. No ore production is recorded although a few tons of low-grade material are piled near the main shaft as though intended for shipment.

The beds are assigned to the Horquilla limestone but the identification is somewhat uncertain because of the metamorphism, the isolation of the area, and the fact that less than 300 feet of beds are exposed. The lowest beds are limestone, which is mainly free from impurities for thicknesses of tens of feet, but which contains a few seams and lenses of silicate minerals. This unit, which is depicted as limestone on the geologic map (fig. 37), is overlain by laminated or mottled lime-silicate rock with subordinate limestone in lenses and narrow

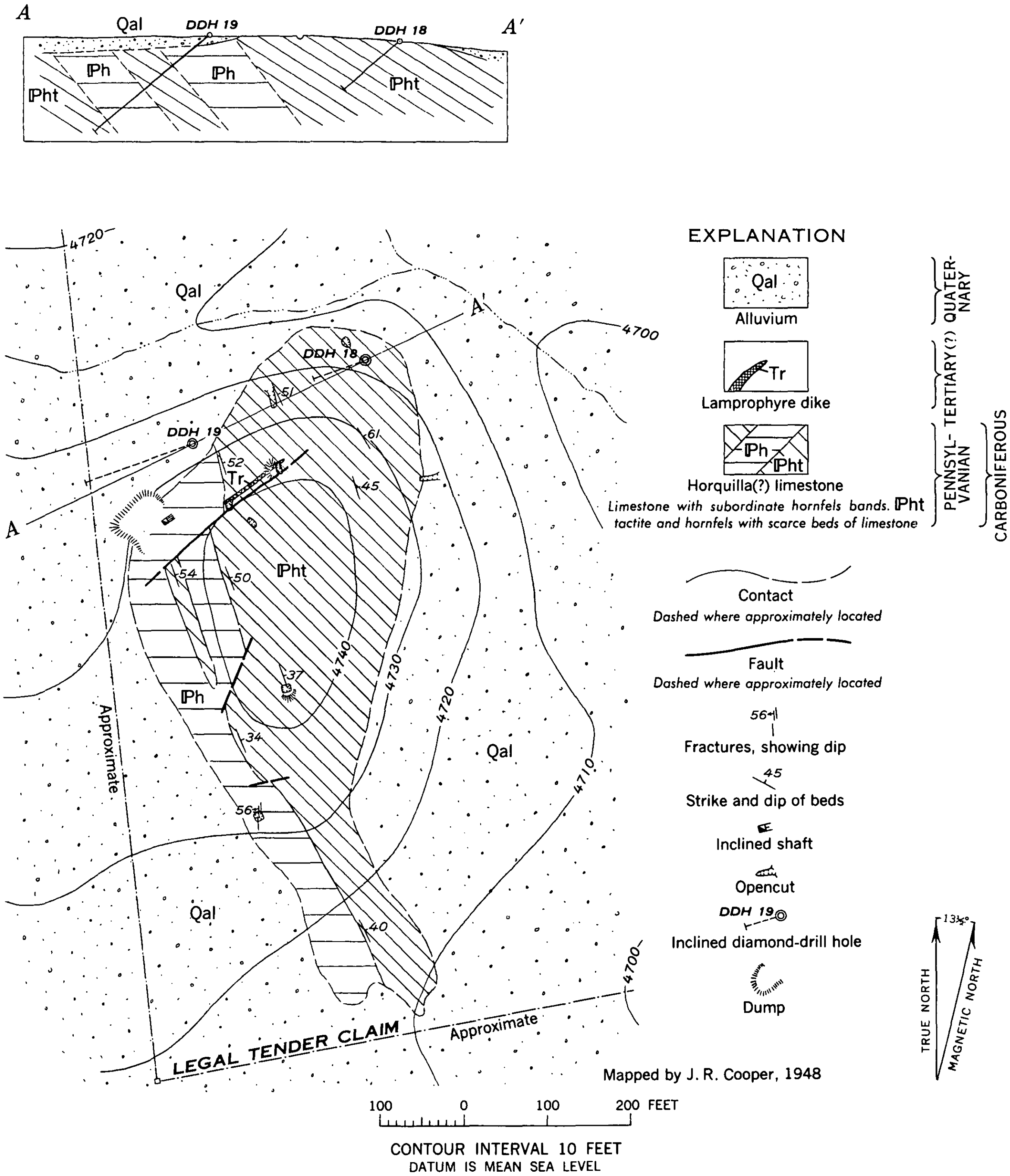


FIGURE 37.—Geologic map and section of the Legal Tender prospect.

bands. Diopside, wollastonite, and garnet are the principal silicates. The laminated tactite is siliceous and evidently represents beds once rich in sand or silt. Several notably spotted layers, probably derived from limestone or dolomite with chert nodules, consist of diopside-wollastonite-garnet rock with dark gray-brown nodules, several inches in diameter, in which fine-grained quartz and biotite are the main constituents. Narrow reaction rims of diopside and quartz surround the nodules. The diamond drilling, described in the following paragraph, revealed considerable dark-brown hornfels not exposed at the surface. Some of this hornfels probably represents chert, for it is indistinguishable lithologically from the dark nodules just described. Much of the hornfels, however, is low in quartz and rich in biotite, muscovite, zoisite, feldspar, and calcite; this association suggests derivation from shale.

The moderately thick bands of pure carbonate rock and bands originally rich in clastic material suggest that the beds are part of the Martin formation, or, more probably, of some formation of the Naco group. If the beds were Martin, almost the whole formation would be exposed and the favorable beds of the Abrigo would lie at shallow depth. Because ore bodies are commonly localized in these favorable beds, and positive identification of the formations would aid in interpreting the structure of a large concealed but potentially mineralized area, it seemed desirable to test the Martin hypothesis. Therefore, it was arranged with the Bureau of Mines, then engaged in a diamond-drilling project on the Keystone and St. George properties, to drill a hole on the Legal Tender claim at Geological Survey expense.

Drill hole 18, drilled under the Bureau's Keystone contract and so numbered in figure 37, was laid out to cut perpendicular to the beds beneath the surface showings; the hole was to be deep enough to determine whether the Abrigo lay below and, if present, what the nature of its alteration was. Difficulties in drilling were found because of hard fractured and caving rock. Frequent cementing was required, and progress had decreased to almost nothing at a depth of 86½ feet where the hole was abandoned. Another hole, 19 on figure 37, was then drilled to secure the desired information.

The logs of the drill holes are as follows:

Diamond-drill hole 18

Location: Legal Tender claim, 310 ft N. 53°15′ E. from main shaft.
Collar elevation: 4,718 ft.
Direction: S. 70° W.
Inclination: 40°.
Length: 86.5 ft.
Drilled: April 29–May 7, 1948 (U.S. Bur. of Mines proj. 1484).

Depth (feet)	*Description*
0–7	Limestone, gray, crystalline; porous breccia zones inclined at about 10° to axis of hole. (57 percent recovery.)
7–24	Tactite, white to pale-blue and brown; largely mottled; several postsilicate breccia zones partly cemented by calcite, silica, chrysocolla, and malachite. (76 percent recovery.)
24–29	Cherty hornfels, dark-brown; recovered as small fragments. (20 percent recovery.)
29–33	Hornfels, pale gray-brown, spotted; lower part soft and cut by seams of calcite and chrysocolla. (62 percent recovery.)
33–41	Limestone; one postsilicate breccia zone at small angle to axis of hole. (10 percent recovery).
41–61	Tactite, mottled gray-green and pink, fine-grained. (30 percent recovery.)
61–63	Cherty hornfels, dark-brown, cut by postsilicate breccia partly cemented by copper-stained calcite and silica. (75 percent recovery.)
63–69	Limestone; includes a little pale-brown garnetiferous tactite. (42 percent recovery.)
69–85.5	Tactite, brown; in part laminated; seamed locally by chrysocolla; cut by breccia zone inclined at about 10° to axis of hole. (30 percent recovery.)
85. 5–86.5	Cherty hornfels, dark-gray. (50 percent recovery.)

Diamond-drill hole 19

Location: Legal Tender claim, 100 ft N. 9° E. from main shaft.
Collar elevation: 4,725 ft.
Direction: S. 70° W.
Inclination: 40°.
Length: 178.5 ft.
Drilled: May 8–14, 1948 (U.S. Bur. of Mines proj. 1484).

Depth (feet)	*Description*
0–8	Soil and caliche. (No core.)
8–20	Alluvium is arkosic sand with boulders of tactite. (13 percent recovery.)
20–25.5	Hornfels, dark-brown, somewhat calcareous; many fracture fillings, thin bands and lenses of calcite and opal; trace of oxidized copper minerals locally. (100 percent recovery.)
25.5–47	Limestone with sugary texture; seams and partly open fissures inclined at 5° to 30° to axis of hole are coated by calcite; trace of iron and copper stain locally. (88 percent recovery.)
47–49.5	Hornfels, mostly calcareous, dark-brown to light-gray or buff. (80 percent recovery.)
49.5–57	Limestone, coarsely cyrstalline. (100 percent recovery.)
57–58.5	Hornfels, calcareous, dark-brown; cut by calcite-silica seams. (100 percent recovery.)
58.5–89	Tactite, fine-grained, nearly white, vaguely spotted, mottled and banded; cut by fractures that are partly cemented by calcite, silica, and a little chrysocolla and malachite. (82 percent recovery.)
89–92	Limestone, gray, crystalline. (67 percent recovery.)
92–102	Tactite, nearly white, fine-grained; with fractures partly cemented by calcite and silica. (80 percent recovery.)
102–126	Limestone, coarse-crystalline; pure except for 1 in. of gray chert near 113. (33 percent recovery.)
126–133.5	Hornfels, dark-brown, calcareous; with bands of gray crystalline limestone and pale-gray to buff hornfels. (67 percent recovery.)
133.5–159	Limestone, coarse-crystalline; pure except for very scarce dark hornfels bands less than 1 in. thick. (51 percent recovery.)
159–178.5	Tactite, nearly white, fine-grained; with lamination almost perpendicular to axis of hole. (82 percent recovery.)

Drill hole 19 is on the west side of the outcrop. If the outcrop were Martin the hole would have penetrated 90 feet or more of the Abrigo, but the lithology is the same throughout the hole and is unlike any part of the Abrigo. The entire sequence is in the Naco group and is probably the Horquilla limestone. The thick beds, alternation of pure limestone, hornfels, and tactite, and the common occurrence of altered chert are typical of parts of the Horquilla limestone in other areas of metamorphic rocks.

STANDARD PROSPECT

The Standard prospect consists of the Standard No. 8 and Standard No. 9 patented mining claims, 2 miles southeast of the Keystone mine. The claims were owned in 1955 by Mrs. Thomas Adams of Dragoon. Two shafts, reported to be 49 feet and 260 feet deep respectively, and a diamond-drill hole were put down on the property in 1908–15 by the late O. T. Smith and associates. No ore was found and both shafts were subsequently filled as a protection for grazing cattle.

The prospect is of interest because the main ore-bearing formation at Johnson, the Abrigo formation, was found there and is mineralized in much the same way as at Johnson. This could not be told from surface exposures, for alluvium covers all formations except the Pinal schist and Texas Canyon quartz monzonite. Favorable and mineralized host rock at the Standard prospect is an encouraging sign for the occurrence of ore beneath the large alluvial area southeast of the Keystone mine and northeast of the Centurion mine. This area and the Johnson area are symmetrically situated with respect to the long axis and principal fissures of the quartz monzonite. Ore has been mined from the Texas Arizona mine to the east, the Centurion mine to the southeast, and tungsten veins to the west.

The surface geology of the prospect and location of the two shafts are shown in figure 38. Most of the material excavated from the old shafts was used in filling them and there are no records of what was found. The only indication of the western shaft is a small pile of copper-stained quartzite, most probably from the Bolsa quartzite. Remnants of the dump from the eastern and deeper shaft consist in part of dark hornfels, which resembles that derived from the lower shale member of the Abrigo formation at Johnson, but contains a little hornblende in addition to the micas and other minerals characteristic of the rock near Johnson.

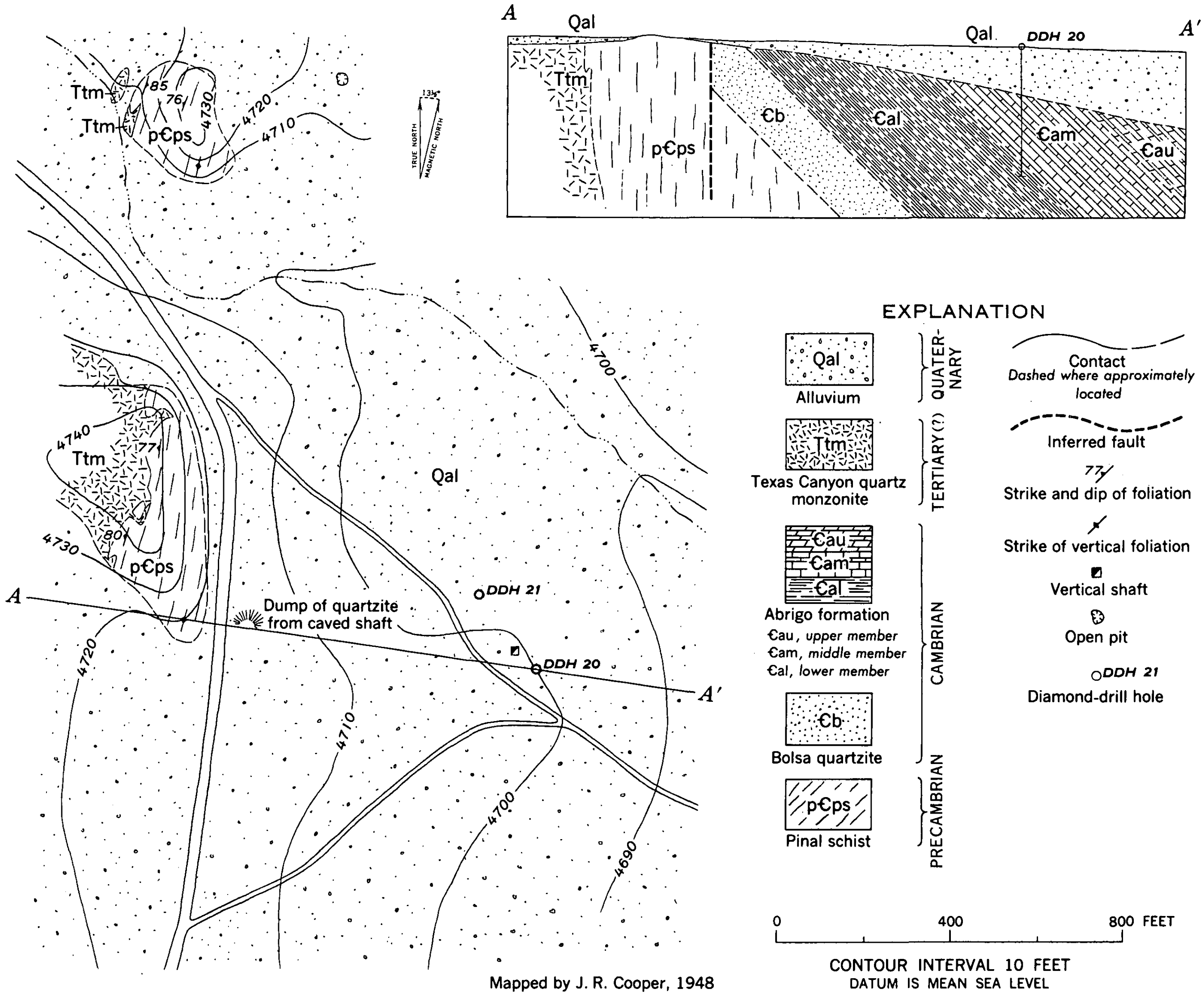


FIGURE 38.—Geologic map and section of the Standard prospect.

It is bleached locally to an aggregate of orthoclase, quartz, and zoisite or epidote; and it contains a few pockets of granular garnet and other lime-silicate minerals. Associated with the hornfels there is recrystallized limestone and much granular garnet-wollastonite rock with subordinate but locally abundant idocrase, diopside, and epidote. Much of the rock is thinly banded. The material suggests the lower or middle member of the Abrigo formation in a slightly higher grade of metamorphism than at Johnson.

To determine whether the deeper shaft did intersect the Abrigo formation and to obtain information on the concealed geologic structure, the Geological Survey located and paid for two short diamond-drill holes, drilled by the Bureau of Mines in connection with its exploration program on the Keystone and St. George properties. The locations are shown in figure 38 and the logs given below. The first hole (D. D. H. 20) substantiates that the bedrock is Abrigo. It appears to have entered unit 4 (113 to 122.5 ft), penetrated units 2 and 3 (123.5 to 275 ft) and part of unit 1 (275 to 301.5 ft). The beds assigned to units 2 and 3 contain in places sparsely disseminated sphalerite, chalcopyrite, bornite, chalcocite, and powellite. The disseminations are not of commercial interest under any conceivable economic conditions, but the ore minerals are more abundant than one would expect from an examination of the dump. Unit 5, which carries most of the ore at Johnson, was not intersected by the drill.

The dip of the beds in drill hole 20, indicated by the inclination of layers to the axis of the core, ranges from 40° to 53° and averages about 45°. The nearby outcrops of Pinal schist and the Bolsa(?) quartzite found in the western shaft are strong presumptive evidence that the dip is to the east as shown on the section (fig. 38). Drill hole 21 was drilled in an attempt to determine the strike by finding the elevation of the contact of unit 1 and unit 2 at that location. The intersected beds dip 55° to 70°, and all seem to belong in units 2 or 3 to a depth of 212 feet where the hole was stopped because of exhaustion of funds available for drilling. If steepening of the dip is the only structural complication between the holes, the most probable strike of the beds is a few degrees west of north.

Log of diamond-drill hole 20

Location: Standard No. 9 claim, 65 ft southeast of shaft.
Collar elevation: 4,700 ft.
Inclination: Vertical.
Depth: 301.5 ft.
Drilled: May 17-24, 1948 (U.S. Bur. Mines proj. 1484).

Depth (feet)	*Description*
0–113	Alluvium is arkosic sand. (No core.)
113–122.5	Garnetiferous tactite, banded and laminated at approximately 37° to axis of hole, rich in orthoclase and quartz. (47 percent recovered.)
122. 5–123.5	No core.
123. 5–165.5	Banded wollastonite-garnet tactite with local concentrations of diopside and orthoclase; specks of chalcopyrite, bornite, and chalcocite in lower 20 ft. (79 percent recovery.)
165.5–184	Interbedded garnet tactite and dark brownish-gray, fine-grained hornfe's; beds 1 ft or less thick inclined near 45° to axis of hole. (59 percent recovery.)
184–198	Same as 165.5–184 ft interval but with hornfels bands thin and scarce. (93 percent recovery.)
198–232	Garnet-wollastonite tactite, in part calcareous, with traces of disseminated sphalerite in 205-222 ft interval. (82 percent recovery.)
232–253.5	Limestone, partly silicated; some shearing and solution channels. (40 percent recovery.)
253.5–259	Tactite, rusty-brown, somewhat limy; much broken and with gouge at 257 ft. (45 percent recovery.)
259–275	Limestone, partly garnetized; includes specks of limonite and traces of copper stain. (38 percent recovery.)
275–301.5	Hornfels, dark brownish-gray to light-gray or green, fine grained, banded, and shaly. (15 percent recovery.)

Log of diamond-drill hole 21

Location: Standard No. 9 claim, 150 ft northeast of shaft.
Collar elevation: 4,695 ft.
Inclination: Vertical.
Depth: 212 ft.
Drilled: May 27-June 3, 1948 (U.S. Bur. Mines proj. 1484).

Depth (feet)	*Description*
0–103	Alluvium is arkosic sand that includes a few boulders of hornfels, tactite, schist, and quartz monzonite. (A few fragments of boulders recovered.)
103–134	Garnet-wollastonite-diopside tactite with a few thin bands of dark, shaly hornfels; beds inclined 20°–35° to axis of hole. (42 percent recovered.)
134–212	Garnet-wollastonite tactite, in part calcareous; bedding planes inclined about 30° to axis of hole; a little disseminated sphalerite, chalcopyrite, bornite, and chalcocite, especially between 155 and 212 ft. (47 percent recovered.)t

GUNNISON HILLS LEAD-SILVER AREA

TEXAS ARIZONA MINE

The Texas Arizona mine, owned in 1957 by Cornelius Chambers and L. C. Chambers of Willcox, is about 4 miles southeast of Johnson and on the west side of the Gunnison Hills at an elevation of 4,845 feet. The mine is developed by an inclined two-compartment shaft, 315 feet long, from which 5 levels have been driven (fig. 39). A vertical shaft, now caved, connected with the second level. Two winzes at the east end of the bottom level, now filled, are said to be 40 and 100 feet deep respectively.

Development began in 1908 and most active mining was in the period 1910–13. Small ore shipments were

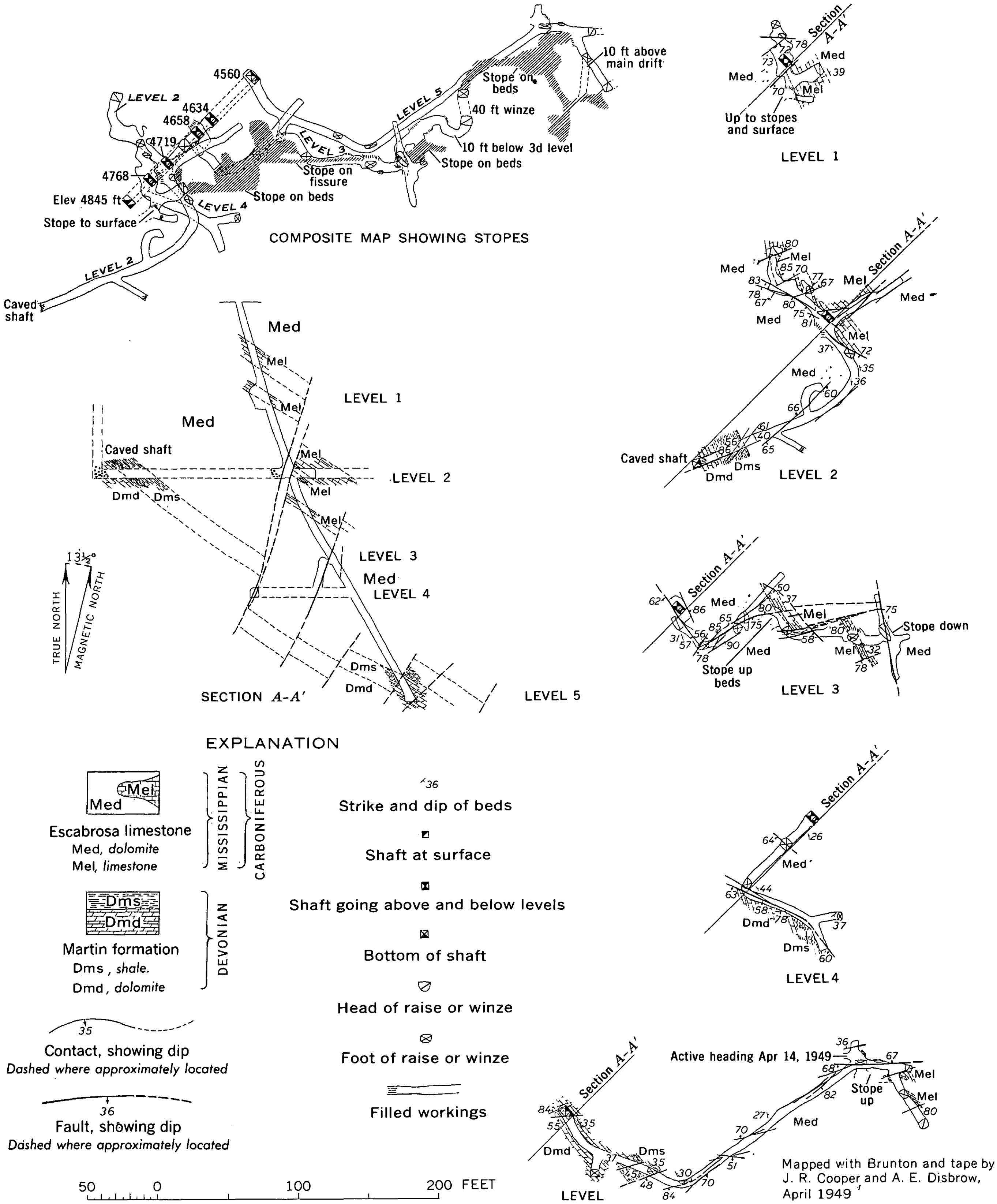


FIGURE 39.—Composite map, geologic level maps, and cross section of the Texas Arizona mine.

made as late as 1928. Total recorded production during the 1910–28 period was 718 tons of ore. The metal content of this ore averaged 38.5 percent lead, 49 ounces of silver, 1.6 percent copper, and 0.05 of an ounce of gold per ton. Small shipments of oxidized zinc ore during the years 1911–13 are included in this total.

The mine workings are in the Escabrosa limestone and uppermost beds of the Martin formation. The beds strike about N. 25° W. and dip about 35° NE. Faults and fissures trend northeast, east, and northwest. The faults trending east and northwest are, on the whole, younger than those trending northeast. The maps and section (fig. 39) show the geologic structure and location of ore bodies that have been found. All these ore bodies were in a zone 80 to 120 feet stratigraphically above the base of the Escabrosa. They are tabular replacement deposits in the upper part of thin limestone units in the dolomite, which characterizes this part of the formation. Streaks and bunches of ore are found also along fault fissures. The largest ore body was found immediately above the third level. This ore body was a lens 90 feet long, 10 to 30 feet wide, and a few inches to 5 feet thick in the top of a limestone bed. The long axis was roughly parallel to the dip of the beds and to the trace of steep northeast fault fissures. This is somewhat oblique to the overall general trend of the ore bodies, which is slightly more easterly than the dip direction of the beds. (See composite map, fig. 39.) The broader trend has no apparent geologic control and may or may not be significant in the search for additional ore.

Oxidation has extended to the bottom level and, according to Mr. Chambers, also to the bottom of the deeper filled winzes which showed a little copper-stained rock but no ore. Cerussite is the principal lead mineral and is associated commonly with anglesite and powdery yellow plumbojarosite(?)—very rarely with traces of green rosasite(?), and deep blue linarite(?). Galena was found in ore fragments on the dump. A little malachite and limonite are invariably present. These minerals occur in bunches, streaks, and disseminations in a gangue of calcite, hypogene quartz, and dolomite.

Small masses of oxidized zinc minerals—willemite, hemimorphite, and hydrozincite—are more abundant in the mine workings than the lead minerals and are much more frequently found along fault fissures than in the bedded replacement ore. The "sand carbonate" along several fault zones near the third level is mainly a mixture of willemite and hemimorphite. These concentrations of zinc without lead probably were formed by deposition from meteoric waters that had dissolved zinc from primary sulfides. Zinc is more soluble than lead in such solutions and, therefore, was carried farther from the site of original deposition.

The mineral that carries silver is not known. Horn silver has been reported (John Walker, oral communication, 1950) but was not identified during our examination. Galena is the only metallic mineral found in polished sections of slightly oxidized ore from the dump. The galena may be argentiferous.

OTHER WORKINGS IN GUNNISON HILLS

In addition to production from the Texas Arizona mine, there has been a very small production (total since 1910 probably less than 100 tons) of lead-silver ore from other places in the northern part of the Gunnison Hills. Most of the prospecting has been on silicified fault zones and narrow quartz-filled fissures which contain base-metal sulfides or their oxidation products. Nearly all the metalized veins are in the Glance conglomerate near Highway 86. The conglomerate here dips southeast at gentle angles and is cut by conspicuous faults, which strike west-northwest and dip 70° to 85° N. These faults seem to be barren of lead though at some places they are slightly silicified and contain limonite and oxidized copper minerals. The lead veins occupy very minor fissures, most of which strike east and dip 50° to 60° N. A few strike northeast and dip about 85° NW. The veins are only 1 to 12 inches wide and at most a few hundred feet long. A little hand-sorted ore has been shipped from pits and shallow shafts. The meager information available indicates that the ore contained 1 to 3 percent copper, 5 to 15 percent lead, and 5 to 20 ounces of silver per ton.

In 1911 the Stroud brothers (Arizona Cleveland Mining Co.) shipped a few tons of high-grade oxidized lead-silver ore from shallow workings about a mile south of the Texas Arizona mine. The workings consist of pits and one short adit in a broad northeastward-trending shear zone in the Escabrosa limestone. The ore probably replaced the limestone, for no vein material was noted, and the reported grade and metal ratios are the same as at the Texas Arizona mine. A little copper stain is the only indication of metalization observed during our survey.

DRAGOON TUNGSTEN AREA

PRIMOS GROUP

The Primos group consists of 21 patented mining claims, extending between the quartz monzonite contact half a mile south of Johnson and a point about a third of a mile southwest of the Bluebird mine, a distance of 2¾ miles (pls. 1, 6). Seventeen of the claims are on the Bluebird vein system; the remaining four claims are strung out along the Yankee Pride vein system which is parallel to the Bluebird system and about 2,000 feet to the southeast. This property was owned by the Primos Chemical Co. for many years and was sold in 1953 to E. C. Walker and K. P. Walker of Dragoon.

The property is the site of the first tungsten discovery in the district, which was in 1898. The property was worked extensively prior to World War I. A gravity concentrator of 5 tons per hour capacity was built in 1915 and it was operated as late as 1917. The peak production was reached early in 1916 when shipments of about 15 tons of high-grade concentrates per week were reported (Eng. Mining Jour., 1916). Since 1918 there has been sporadic mining by lessees.

Workings include the Bluebird mine, Dividend tunnel, and a few smaller adits and shafts, but most of the production probably came from scores of open pits and small underhand stopes on the vein outcrops. The surface debris on the slopes below some of the veins has been worked also.

BLUEBIRD MINE

The Bluebird or Primos mine is the largest tungsten mine in the Dragoon quadrangle. It is 2¾ miles southwest of Johnson at an elevation of about 5,350 feet on the north slope of Bluebird Hill, the highest hill on the Bluebird vein system. The mine was operated before and during World War I, but there is no record of more recent mining. The following brief description has been taken largely from U.S. Geological Survey data obtained in 1943 by Konrad Krauskopf and Robert Stopper.

The mine is opened by several tunnels driven southwestward into Bluebird Hill along veins which are also exposed on the slope above. The workings include about 1,400 feet of drifts, 350 feet of crosscuts, four 30-foot winzes, one 40-foot raise, and stopes from which about 7,500 tons of rock have been removed. Five drifts explore a succession of parallel veins on one level and a sixth follows roughly the intersection of two veins at a lower level. (See pl. 13.)

The veins are narrow, irregular in width, often pinching out along the strike, and branching into tiny stringers. The thickness of veins stoped ranges from a few inches to 2 feet and averages 6 or 8 inches, as far as can be told from the present workings. As the stopes are several times this width it is clear that considerable waste was mined with the ore. The veins fall into two main sets; most of the veins dip 60° to 70° SE., but some dip 35° to 50° SE. Where veins and fractures of the two sets meet, either one curves into the other or the flatter structures cut the steeper ones. Shearing and striae in the veins indicate several directions of movement, but the most conspicuous striae rake eastward and suggest reverse movement.

The mine is said to have yielded rich ore. According to John Walker (oral communication, 1950), one fragment of nearly pure huebnerite weighing 2,200 pounds was taken out, crated, and shipped in one piece. One ore shoot mentioned by Wilson (1941, p. 42) is said to have yielded 5½ tons of huebnerite.

Tungsten minerals are scarce in the parts of the veins now visible. Pillars in the stopes probably contain less than half a percent of tungsten trioxide and the walls and roofs of the stopes are generally leaner. The best remaining ore is at the southwest end of the lower level, in a short crosscut which partly explores several complexly branching veins. (See pl. 13.) Lower grade material is found almost directly above in the vein at the southwest end of drift 3. The quartz at both localities is locally as much as 2 feet wide. The vein at the west end of the lower level and also exposures at the surface suggest that the vein in drift 2 may reappear farther to the southwest in ground not now explored.

No relation between structure and concentration of ore was observed. Two stopes are on gently dipping veins, three on steep veins. Pockets of huebnerite occur in thick parts and very narrow parts of the veins. Although cross fractures are present, neither the amount of visible ore nor the extent of stoping suggests that they influenced ore deposition. Exposures of vein intersections and abrupt turns in the veins show few unusual concentrations of ore minerals.

DIVIDEND TUNNEL

At the Dividend tunnel, which is 3,000 feet northeast of the Bluebird mine, the Bluebird vein system is characterized by an unusually large concentration of small veins across a width of 50 to 75 feet. The individual veins are rarely as much as 2 feet wide and none seems to extend more than 150 feet along the strike. The veins make up about 10 percent of the mineralized zone but are concentrated locally into lodes 4 or 5 feet wide containing as much as 40 percent of vein material.

The principal veins strike N. 30° to 40° E., nearly parallel to the mineralized zone as a whole, and dip 40° to 60° SE. A subordinate set of veins strikes N. 5° to 20° E. and dips about 45° E. Where veins of the two sets meet, the weaker vein merges with the stronger. The N. 5° to 20° E. veins in places form S-shaped linkages between the northeastward-trending veins. Shearing and striae in and along the margins of the veins indicate complex fault movements. Evidence suggesting reverse movements nearly parallel to the dip was noted on the more northerly trending veins; whereas evidence of normal movements parallel to striae raking 40° to 75° SW. are common on the northeastward-trending veins. The vein pattern suggests that the reverse movements preceded the normal movements.

A few unmineralized faults which dip south offset the veins a few inches.

The mineralized zone is developed by large opencuts on the surface and by a crosscut adit, 185 feet long and about 25 feet vertically below the vein outcrops. From the crosscut, 5 drifts totaling about 500 feet have been driven. A northeastward-trending lode along the east or hanging-wall side of the mineralized zone was mined above the adit level, at places to the surface. The lode was mined for a length of about 200 feet and is in most places 4 or 5 feet wide. Apparently about 2,000 tons was removed, but this estimate is somewhat uncertain because parts of the stope are caved and inaccessible.

OTHER WORKINGS

Other workings on the Primos claims include many opencuts and a few shallow shafts and tunnels. Near the top of Bluebird Hill, a 40-foot shaft with a 60-foot drift at the bottom follows a 4- to 18-inch vein which dips 39° SE. About 150 feet farther west, a 130-foot crosscut tunnel now partly caved cuts through the hill. Still farther west, on the Yellow Jacket claim, 3 crosscut adits, 2 of which are caved at the portal, enter the hill from the south side; these adits are 50 to 125 feet vertically below the outcrop of the mineralized zone. A little ore is said to have come from these adits.

The general character and attitude of the veins in the long northeastward-trending segment of the Bluebird vein system are like those in the Bluebird and Dividend mines, though the ratio of vein material to barren rock varies from place to place. About 1½ miles northeast of the Bluebird mine, the vein system, as a whole, swings from N. 50° E. to N. 15° E (pl. 6). Near the bend there are several small intrusions of aplite and the pattern of veins is complex. Conspicuous in the complex zone are several short northwestward-striking veins, one of which is relatively thick (4 ft). North of the bend thin (3- to 18-in.) but relatively long veins have a remarkably consistent attitude (N. 15° E., 60° to 80° E.) that is parallel to the Northeasters at Johnson. The best mineralized veins are in a zone 100 to 600 feet wide extending nearly to the quartz monzonite contact where the vein system dies out. These veins have been mined by pits and opencuts.

The Yankee Pride vein system parallels the Bluebird vein system on the southeast and is on the high ridge just north of Highway 86. The workings along the system consist of one 40-foot adit (Yankee Pride), and opencuts strung out for about a mile along the ridge. A few of the workings are on the crest but most are a short distance down the north slope. The workings have yielded about $26,000 in tungsten concentrates, according to Mr. Boericke of the Primos Chemical Co.

The veins in the Yankee Pride system are said to have been leaner than those in the Bluebird system, but little difference in tungsten content or size was noted in the field. The veins are in two sets. One set strikes about N. 45° E. parallel to the system as a whole and dips 50° to 70° S.; the other set consists of en echelon veins which strike N. 60° to 75° E. and dip 40° to 60° S. The relation of en echelon veins is opposite that in the Bluebird system where the en echelon veins have a more northerly strike than the vein system and dip to the east. This difference in pattern and the fact that striae indicate reverse movement in the Bluebird but normal movement in the Yankee Pride suggest that the block between the vein systems was uplifted with respect to the blocks on the two sides.

LITTLE FANNY GROUP

The Little Fanny group of 14 unpatented claims, once known as the Extension group, adjoins the Primos property on the southwest and includes the extension of the Bluebird vein system and a small parallel vein system about a thousand feet to the southeast. The claims are said to have been located by Asa Walker in 1898 (J. J. Wien, oral communication, 1949). They were worked during the early years of this century and particularly during World War I. In the period 1934–39 a production of 30 tons of concentrate is reported (Wilson, 1941, p. 42–43). The claims have been idle since 1940. In 1954 they were held by Mr. Joseph Robles of Tombstone, Ariz.

The property is developed by many pits and opencuts, 5 to 20 feet in depth, and several adit tunnels totaling about 1,600 feet in length. The adits and the greatest concentration of opencuts are in a 1,200-foot segment of the Bluebird system just east of the road to the property (pl. 6). Two adits, shown on plate 13, explore the ground 50 and 80 feet vertically below the surface exposure of a 2½-foot vein. Another adit, which is now mostly caved, is a crosscut entering fresh quartz monzonite about a thousand feet to the northeast and 100 feet vertically below the mineralized outcrops. There are small caved stopes above this adit and the upper adit shown on plate 13.

The Bluebird system on this property, as on the adjacent Primos claims, is characterized by many quartz veins 1 to 8 inches thick and a few feet to 200 feet long. A few individual veins widen locally to 2 or 2½ feet, and at a few places veins are close enough together to constitute lodes several feet wide. Three moderately well defined sets of veins may be distinguished. The most abundant and productive veins strike about N. 45° E. and dip about 70° SE. Other sets of veins, which have been mined locally, have attitudes near N. 15° E., 40° to 60° E. and N. 65° E., 80° S. respectively. A relatively strong vein in one set commonly has small offshoots that belong in another set, and a few veins bend sharply from one of the preferred attitudes to another. The stoped vein shown on plate 13 may be an example of the latter relation. This vein belongs in the N. 45° E. set where it was mined above the upper adit. Either it dies out completely above the lower adit, or it is represented by the strong (but nearly barren) N. 15° E. vein in the eastern end of the lower adit level.

Minor fault movements were contemporaneous with vein formation, for some veins are sheared, others unsheared, and a few consist of an earlier sheared part and a later unsheared part. Tungsten minerals seem about equally abundant in sheared and unsheared veins. The shearing movements represent adjustments between small blocks, and no set of faults is consistently younger than another. The displacement of any particular vein or unmineralized fault was at most a few inches as determined by the offset of one structure by another. All movements appear to have been of the normal type.

About a thousand feet southeast of the Little Fanny mine there is a satellitic vein system 2,000 feet long and 150 feet wide, parallel to the Bluebird system. Nearly all the veins in this part of the property are in the N. 65° E. set and are arranged en echelon. The largest of these veins is 150 feet long, locally as much as 2½ feet wide, and has been mined by an opencut to a depth of 20 feet. The other veins are a foot or less thick.

HAWK GROUP

The Hawk group of 6 claims is half a mile southeast of the Little Fanny property and includes several small vein systems parallel to the Bluebird system. These claims have been held in recent years by J. J. Wien of Benson. According to Mr. Wien, the claims were located by Asa Walker in 1898 and worked by P. M. Sebring during World War I; in the period 1933–39 they yielded about 5 tons of concentrates (Wilson, 1941, p. 43). Production by lessees between 1939 and 1943 may amount to a few additional tons of concentrates.

Both vein and placer deposits have been worked on the property, which is developed by opencuts and several short adits and shallow shafts. The most extensive workings are on a vein exposed just east of Texas Canyon Wash, 4,000 feet north of the Triangle T Ranch. This vein, which strikes N. 38° E. and dips 73° SE., is 2 to 3 feet thick and traceable for about 200 feet at the surface. Although the vein appears to be short, it has clear-cut walls at most places and is one of the thickest tungsten-bearing veins anywhere in the quartz monzonite. It is developed by surface workings and an inclined shaft down the dip. The shaft, which is known as the Hawk shaft, is not readily accessible. According to Mr. Wien (oral communication, 1948), it is 80 feet deep and has ore at the bottom. Drifts from the shaft are probably not extensive.

The vein just described and smaller parallel veins in the vicinity are characteristically somewhat sheared and have striae raking 25° to 50° NE. The direction of displacement was not determined, but reverse movement is suspected because the displacements along other vein systems in the quartz monzonite generally involved right-lateral movement and because the thickest part of the vein at the Hawk shaft is in a flatter dipping segment about 20 feet below the surface. Two small lamprophyre dikes trending a few degrees west of north cut quartz veins 100 and 200 feet southwest of the Hawk shaft respectively.

Except near the Hawk shaft, the property is characterized by southward-dipping en echelon veins striking about N. 70° E. These veins are very rarely as much as a foot wide but carry tungsten and have been explored and mined locally.

BANKS VEINS

The Banks veins are approximately 2 miles due east of the Bluebird mine in the southern part of sec. 1, T. 16 S., R. 22 E. (pl. 1). Ownership was consolidated by eastern capitalists in 1899 soon after a tungsten strike by John Miller ("Willcox Star," Mar. 29, 1899). The veins were worked during World War I by Mr. Banks and associates, who had a concentrator near Russellville. Total tungsten production was small, according to local residents.

Development consists of pits and inclined shafts, 4 of which, though now inaccessible, are probably 50 to 100 feet deep. Most of these workings are along a quartz vein about 4,000 feet long and locally as much as 4 feet wide that strikes N. 70° E. and dips 40° to 60° S. The vein is slightly sinuous in strike. The thickest segments are in two gentle northward bends; the vein thins and may pinch out locally in two southward bends. The quartz carries huebnerite, scheelite, fluorite, muscovite, and base-metal sulfides. The average tungsten content is low. The richest ore appears to have been found at the most conspicuous northward bend, in small veins parallel to the main vein, and 25 to 50 feet from it on the footwall side.

A short distance south of the vein just described, there is another tungsten-bearing quartz vein, 1,800 feet long and locally as much as 6 feet wide, that strikes N. 45° E. and dips about 65° SE. It is developed by shallow pits and, near the east end, by an inclined shaft perhaps 50 feet deep. On the northeastern projection of the vein are small en echelon veins striking N. 10° to 20° E.; and on its southwestern projection small N. 45° E. veins appear at intervals for several thousand feet.

OTHER DEPOSITS IN THE NORTHERN PART OF THE QUARTZ MONZONITE STOCK

Other tungsten deposits that have been found in the northern part of the Texas Canyon quartz monzonite stock are few and all of minor importance. About a mile north of the Banks veins, in the NE¼ sec. 2, T. 16 S., R. 22 E., some ore has been mined from one 40-foot incline and many opencuts, 5 to 15 feet deep. The ore was obtained from small quartz veins and lodes that trend northeast. The individual veins are generally less than 1 foot wide and 200 feet long. The lodes are at most 2 or 3 feet wide and several hundred feet long. Conspicuous north-to-northwestward-trending veins in the eastern outcrops of the quartz monzonite of this general area are barren or low in tungsten.

A mile northwest of the Little Fanny mine in the southeast corner of sec. 5, T. 16 S., R. 22 E., a northeastward-trending quartz vein 1,800 feet long has been mined for tungsten in a small way. (See pl. 1.) The vein is practically vertical and parallel to well-developed unmineralized joints in the vicinity. It varies erratically in width from a few inches to several feet. It is sheared in places. The minerals are the same as in other veins in the northern part of the quartz monzonite. Development consists of opencuts, 8 to 12 feet deep, along the outcrop and a short adit on the vein. A few other tungsten-bearing veins, also nearly vertical and striking northeast, are found within an elliptical area roughly 4,000 by 2,000 feet that surrounds this vein. These veins, which are too small to show on the geologic map, have been explored to a limited extent by pits and shallow shafts. The largest opening is 600 feet northwest of the adit previously mentioned and consists of an opencut, 2 feet wide, 30 feet long, and 20 feet deep.

DEPOSITS SOUTHWEST OF THE CENTURION MINE

A little tungsten has been produced from quartz veins west and southwest of the Centurion mine. These veins contain on the whole considerably less tungsten than those farther north. Scheelite is considerably more abundant than huebnerite and in places is the only tungsten mineral present. The scheelite is difficult to detect except by its fluorescence under ultraviolet light. Several small masses of scheelite ore that we found in this way certainly would have been mined if the scheelite had been recognized by the early prospectors.

Quartz veins are very abundant in the marginal part of the quartz monzonite for about a mile southwest of the Centurion mine. Narrow vein systems, marked by bands of alteration in the quartz monzonite (pl. 1), trend westward from the quartz-rich marginal zone. The dominant vein systems trend nearly due west and extend 1 to 2½ miles inward from the contact. Other vein systems trend about S. 60° W. The veins are, at maximum, 5 feet wide and 800 feet long but most are much smaller. The predominant strike, particularly of the smaller veins, is northeastward, in a more northerly direction than the trend of the vein system in which they occur. The en echelon veins appear to follow planes of shear and therefore suggest relative westward displacement of the southern block. At 3 or 4 places within the dominant vein system, it was noted that northeastward trending en echelon veins had an S-shape, indicating this kind of movement. Some of the veins are sheared and have striae raking eastward.

Examination of many veins in this area under ultraviolet light has shown that traces of scheelite are common east of the meridian of the Triangle T Ranch. The scheelite is not confined to the quartz veins but occurs also in association with fluorite in the adjacent silicified and muscovitized quartz monzonite. Several relatively rich concentrations without associated huebnerite were near a limestone inclusion 3,300 feet west-southwest of the Centurion mine. At one place in this area, the tungsten content was estimated at 2 percent WO_3 across a width of 4 to 5 feet. Excavation would be required to determine the other dimensions of this body. Another concentration of scheelite, estimated to contain 0.25 to 0.75 percent WO_3, was noted on the dump of a 25-foot inaccessible shaft on the quartz monzonite contact 2,200 feet west-southwest of the Centurion mine. The shaft is in silicified contact breccia exposed for a width of 4 feet. Weak copper stains along cracks in the breccia and adjacent limestone appear to have been the lead that was followed. Only traces of scheelite are to be seen at the surface. The tungsten-bearing material on the dump is silicified quartz monzonite breccia with disseminated scheelite and purple fluorite.

DONNA ANNA VEINS

Northeastward-trending quartz veins, here called the Donna Anna veins, are found in the Pinal schist ½ to 1¼ miles southwest of Johnson and 1,000 feet or less from the quartz monzonite. (See pl. 6.) The veins are opened by cuts and shallow shafts, which have evidently yielded tungsten. The largest working is a cut, 20 feet deep, with a short drift at the bottom, on the Donna Anna claim. This claim was patented in 1882, presumably on the basis of copper showings, and is now owned by the Coronado Copper and Zinc Co.

The individual veins are a few inches to 2 feet wide and 100 to 800 feet long. Mapping suggests that one fissure was mineralized at intervals for 3,500 feet. The veins strike N. 50° to 85° E. and dip steeply, generally to the south. Many are strictly parallel to the schistosity of the wall rocks, but others cross the schistosity at small angles along shear planes. Coarse-grained grayish-white quartz is the principal mineral and contains local concentrations of huebnerite and a little scheelite. Traces of powellite were found in one of the veins. Small amounts of pyrite, chalcopyrite, and galena are common as are iron and manganese oxides. Compared with veins in the quartz monzonite: muscovite is scarce; fluorite was not observed; huebnerite generally occurs in smaller crystals; and manganese oxides are more abundant.

HOMESTAKE DEPOSITS

The Homestake group of four unpatented mining claims was located by J. J. Wien and A. H. Yeagley in 1931 near the western boundary of sec. 5, T. 16 S., R. 22 E. A small amount of exploratory work was done, but apparently no ore was produced. The deposits have been idle since 1944 or earlier.

The principal deposits are in an amphibolite (metabasalt) unit of the Pinal schist half a mile from the Texas Canyon quartz monzonite contact (pl. 1). The amphibolite is a lenticular mass, locally as much as 500 feet wide, lying parallel to the schistosity, which in this area strikes northeast and dips about 70° NW. The mass is exposed for a length of 1,800 feet and is in fault contact with late Precambrian rocks at the west end. It is cut by small irregular dikes of aplite, presumably of Tertiary age. The amphibolite has been mineralized here and there in lenses a few inches to a foot or two wide. The mineralized lenses consist of coarse quartz, epidote, garnet, grayish-green amphibole, and disseminated scheelite. A little chalcopyrite and oxidized copper minerals are generally present and Wilson (1941, p. 44) reported a little gold also. These deposits have been prospected by a few shallow pits, a short adit, and a shaft about 40 feet deep.

About 1,500 feet from the quartz monzonite contact on the Homestake No. 1 claim, a group of 4- to 24-inch quartz veins, cutting the Abrigo formation, have been explored by several 10-foot pits. These veins contain pyrite, calcite, and apparently a little fluorite and scheelite. They strike about N. 60° E. and dip steeply southward. They are 100 to 250 feet long and are arranged en echelon near the large northward-trending fault that here bounds the Paleozoic rocks. The veins cut small northwestward-trending faults in the Paleozoic rocks.

BURRELL CLAIMS

A group of 26 claims in the area of Paleozoic rocks southwest of Dragoon was held in recent years by Lynn Burrell of Dragoon. The claims were located many years ago for copper. Many pits and shafts were sunk before and during World War I, and a few small shipments of copper-silver ore were made. Tungsten seems to have been known for a long time, for Wilson (1941, p. 44) reported that 100 pounds of tungsten ore was shipped from an old dump during World War I. About 1940, B. E. Gilbert, a lessee, shipped 400 pounds of scheelite concentrates.

The scheelite shipped by Mr. Gilbert was obtained from a small vein cutting the Horquilla limestone several hundred feet west of the Empire No. 2 shaft. The vein, which strikes N. 50° E. and dips 75° to 80° NW., is 4 to 18 inches wide and may be traced for about 250 feet northeastward from alluvial cover. It consists of coarsely crystalline grayish-white quartz, buff to deep-brown calcite, irregular grains of straw-colored scheelite, and locally contains abundant sulfides of lead, copper, iron, and zinc, together with their oxidation products.

Development of the vein, at time of our mapping in 1947, consisted of an old 40-foot shaft with perhaps 50 feet of drifts and a more recent opencut about 15 feet deep.

TUNGSTEN KING MINE

The Tungsten King mine is on the steep western slope of the Little Dragoon Mountains in Clark Canyon at an elevation of 5,250 feet. It may be reached by automobile via Pomerene in the San Pedro Valley.

The mine is the principal working on a group of 12 mining claims, long known as the Tungsten King group but now called the Black Rock group, that extend from Hughes Canyon southward for about a mile. Scheelite was discovered on this property in 1913 by J. J. Wien of Benson. During World War I the deposits were extensively developed by opencuts and short adits which, according to Mr. Wien (Wilson, 1941, p. 43), yielded 5 tons of high-grade scheelite concentrates. The largest deposit at the Tungsten King mine was further developed about 1930 by a crosscut adit and short drifts. Apparently little if any tungsten was produced at that time.

Miles Carpenter leased the property in 1937 and produced about 800 pounds of scheelite concentrates (Wilson, 1941, p. 43) before operations were suspended in 1941. The Kramer Mining and Milling Co. resumed mining in 1952 and built a small gravity mill at Pomerene. Late in 1953 the Standard Tungsten Corp. bought the property, built a new concentrator at Pomerene, and continued mining. Production from 1952 to October 1954 was 12,650 pounds of concentrates, according to the owners. Thus, total reported production to October 1954 was 11¾ tons of concentrates containing roughly 750 units of tungsten trioxide.

All production since 1930 and part of the earlier production came from the Tungsten King mine.

The Tungsten King mine is on the King vein which here strikes north and dips 45° to 50° E. and is between Tungsten King granite on the west and Pinal schist on the east. Early mining was from opencuts. The largest and evidently most productive of these cuts were on a segment of the vein, about 125 feet long and 1 to 5 feet wide, just south of a cross fault that offsets the vein approximately 80 feet at the surface (pl. 13). The adit, which was driven about 1930, reaches the vein about 100 feet vertically and 130 feet downdip from the best mineralized outcrops. A drift was driven southward along the vein; the faulted northern segment also was found and followed a short distance northward. At the time of our mapping in 1952 the workings in the northern segment were completely caved and the south drift was caved 80 feet from the crosscut (pl. 13). Small stopes had been opened above the south drift.

In October 1954, Dr. H. S. Hu, president of the Standard Tungsten Corp., informed us that the old stopes had been extended to the surface; the south drift had been reopened and extended to a total length of 290 feet, and the northern vein segment had been followed for a length of 215 feet. According to Dr. Hu, the character of the vein is virtually the same for the distance developed.

The width of the vein, insofar as we could observe it at the surface and underground, ranges from 6 inches to 5 feet and averages about 3 feet. It consists of quartz, altered and injected lamprophyric dike rock, small pockets of pale-brown calcite, disseminated scheelite, cubic pyrite, galena with exsolved tetradymite and a little beryl and chalcopyrite. The oxidized parts contain a little limonite, jarosite, and wulfenite; cubic cavities formed by leaching of pyrite are common.

The tungsten content of the vein is erratic. Some samples across the vein contain 1 to 2 percent WO_3 and other less than 0.1 percent. The average of ore mined in the period 1952–54 is probably close to 0.5 percent. Mill recovery since 1952 has been 6.6 to 8 pounds of concentrate per ton. The concentrates are said to contain 60 percent or more of tungsten trioxide, but some have required later flotation treatment to get rid of excess sulfur, lead, copper, arsenic, and phosphorus.

To obtain some idea of the beryllium content of the vein, six samples were collected in 1949 by W. T. Holser of the Geological Survey. These samples were taken from vein outcrops near the mine and farther north and contained between 0.0008 and 0.052 percent BeO (Warner and others, 1956, p. 97). The tungsten content ranged from 0.0016 to 0.1340 percent, without any evident relation to the beryllium content. Two additional samples were taken from the south drift at the time of our underground mapping. Quantitative spectrographic analyses of these samples indicated 0.0043 and 0.0027 percent beryllium and 1.1 and 0.24 percent tungsten, respectively.

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