General Geology of Central Cochise County Arizona

By JAMES GILLULY

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With sections on age and correlation by A. R. Palmer, James Steele Williams, and J. B. Reeside, Jr.

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GENERAL GEOLOGY OF CENTRAL COCHISE COUNTY, ARIZONA

By James Gillully

ABSTRACT

The area described in this report comprises the western two-thirds of the Pearce quadrangle and the eastern two-thirds of the Benson quadrangle of the Geological Survey's Topographic Atlas of the United States and includes about 1,400 square miles in the west-central part of Cochise County, Ariz. The town of Tombstone lies near the center of the area.

Cochise County is in the southeast corner of the State, and embraces a part of the Mexican Highland section of the Basin and Range province. The San Pedro Valley lies along the western border of the area; the Sulphur Spring Valley along the eastern. Most of the intervening divide is formed by the Dragoon Mountains, which enter the map area at the middle of the northern boundary and extend south and southeast for about 20 miles, and the Mule Mountains, which enter at the middle of the southern boundary and extend northward for about 6 miles. The divide between these two ranges is an inconspicuous part of the desert plain dotted with disconnected low hills. The Tombstone Hills in the San Pedro Valley and the Pearce Hills in the Sulphur Spring Valley lie well out in the bordering troughs. This report is primarily concerned with the geology of the upland areas; only incidental work was done in the valley and piedmont areas, and no attempt has been made to study the latest formations of Tertiary and Quaternary age within them in the detail warranted by their interest.

The rock formations of the area range from pre-Cambrian to Recent. The oldest rock exposed is the pre-Cambrian Pinal schist. It contains several small intrusive masses of albite granite, quartz diorite, gneissic granite, and saussuritic quartz monzonite which are also referred to the pre-Cambrian. The Cambrian is represented by the Bolsa quartzite and Abrigo limestone. The Martin limestone, of Late Devonian age, rests directly upon the Abrigo limestone. The Mississippian is represented by the Escabrosa limestone, dominantly of early Mississippian age but possibly containing some upper Mississippian rocks also. The higher rocks of Paleozoic age were formerly assigned to the Naco limestone of Pennsylvanian age. In this report, the Naco is regarded as a group and has been subdivided into four formations. These are, in ascending order, the Horquilla limestone (lower and lower upper Pennsylvanian), the Earp formation (upper Pennsylvanian and Permian?), the Colina limestone (Permian? and Permian), and the Epitaph dolomite (Permian).

Five intrusions have been referred to post-Paleozoic–pre-Cretaceous time, one on incontrovertible evidence, the others on indirect bases. These rocks range petrographically from granite through quartz monzonite and alaskite to monzonite porphyry. There is also a volcanic formation that is perhaps referable to this epoch.

In the Mule Mountains the Cretaceous is represented by the Bisbee group, of Comanche age: Glance conglomerate, Morita formation, Mural limestone, and Cintura formation. These subdivisions cannot be recognized elsewhere in the area, so that except in the Mule Mountains the Bisbee is regarded as a formation rather than a group.

Two small intrusive masses of granite and granite gneiss are regarded as either of Late Cretaceous or early Tertiary age. Also belonging to this time are two series of volcanic rocks: the Bronco volcanics (andesite and quartz latite) in the San Pedro Valley and the Sugarloaf quartz latite, also with associated andesitic rocks, in the southern Dragoon Mountains and Sulphur Spring Valley.

In the interval between the beginning of the Tertiary and the early Pliocene, four recognizably different intrusions were emplaced in the southwestern part of the area; still another major granite mass, the Stronghold granite, was emplaced in the northern part of the Dragoon Mountains; and land-laid sedimentary rocks, overlain by two distinct series of volcanic rocks, were deposited. The volcanic formations include the S O volcanics in the southern Dragoon Mountains and the Pearce volcanics farther north.

In Pliocene time the Gila conglomerate was deposited in the valley of the San Pedro River. Basalt, both intrusive and extrusive, of about this age has also been recognized. Quaternary deposits include alluvium, sand dunes, and playa clays.

The geologic structure of the area is complex and its elucidation hampered by the dearth of fossils of age intermediate between the Comanche and late Pliocene.

The schistosity of the Pinal schist, though irregular, strikes generally northeastward or eastward, recording a pre-Cambrian orogeny of presumably parallel trend, though any detailed analysis is prevented by the cover of younger rocks. It may be noted that such trends are common in the pre-Cambrian rocks of a large part of southeastern Arizona.

Post-Paleozoic and pre-Cretaceous deformation is recorded by high-angle unconformity and granitic intrusions in the Mule Mountains, by an erosional unconformity and mild discordance in the Tombstone Hills, very probably by intrusions of quartz monzonite, monzonite porphyry, and granite in the southern Dragoon Mountains and by angular unconformity and quartz monzonite in the northern part of the Dragoon Mountains. There is a suggestion of a northeasterly trend of the structural axes of this deformation, but this cannot be considered established.

The post-Comanche epochs of deformation cannot be placed accurately in the geologic time scale because of lack of paleontologic evidence as to the age of the several formations concerned; there is, nevertheless, definite evidence of more than one such epoch. To the earliest of these is referred the mild unconformity beneath the Bronco volcanics and the intrusion of granitic rocks in the northern Dragoon Mountains and in Ash Creek Ridge in the Sulphur Spring Valley. It is a reasonable presumption that the Sugarloaf quartz latite is also unconformable with the older rocks, but it has not been found in depositional contact with them.

The most profound deformation of the area took place after the Bronco volcanics and Sugarloaf quartz latite were erupted. This involved great thrust faults of northerly to northwesterly trend in the Dragoon Mountains and the overturning of a section of the Bisbee formation fully 3 miles thick along the eastern flank of this range. A gigantic breccia of fragments of nearly every older formation exists in the Courtland and Gleeson areas. It suggests that the major fault was, in this section of its exposed course, advancing over the surface, producing the breccia by attrition of the overriding thrust plate. Minor thrust fragments of this age are found in the Tombstone Hills, and there is other evidence that the Uncle Sam porphyry here is in part a sill-like sheet injected along a thrust surface. A peculiar zone of eastward-trending faults probably records some shortening along the northern side of the Mule Mountains during this epoch, but its divergent trend makes it seem referable to a different, perhaps earlier, substage of the deformation.

The Stronghold granite is younger than the thrusting and has domed the thrust sheets slightly. This doming does not appear, however, to account for the emplacement of the granite, which is clearly transgressive. In the Tombstone Hills the Schieffelin granodiorite seems also to be younger than all important compressional stresses, as is the Uncle Sam porphyry. The S O volcanics and Pearce volcanics have been tilted and faulted; and presumably such faults also affected the older rocks, though no consistent system has been recognized in the volcanic rocks. Hence, such faults as may have occurred at this time in the older rocks cannot be recognized as having been formed at the same time as those in the volcanic rocks. It is possible that these faults in the youngest volcanic formations were formed at the time when the present mountain masses were blocked out—just prior to the deposition of the Gila conglomerate in Pliocene time. Further faulting occurred during the deposition of the Gila conglomerate, as is shown by mining explorations in the Tombstone district; but no evidence of Recent faulting has been recognized in the area. It is concluded that the latest movements on the Basin and Range faults of the area are considerably older than those in many parts of the Basin and Range province farther west and north.

Pediments of two cycles have been recognized in the San Pedro trough. The lower of these has been deeply dissected in Recent time by the San Pedro River, and the flood plain of the river has been still further trenched since the early settlement of the region.

INTRODUCTION

LOCATION, CULTURE, AND ACCESSIBILITY

The area described in this report, comprising about 1,400 square miles, in west-central Cochise County, Ariz., is embraced between the parallels 31°30′ and 32° and the meridians 109°40′ and 110°20′. (See fig. 1.) It thus covers the western two-thirds of the Pearce quadrangle and the eastern two-thirds of the Benson quadrangle of the Geological Survey's Topographic Atlas of the United States. The southern limit of the area passes about 4 miles north of the great mining town of Bisbee and is about 11½ miles north of the Mexican boundary. The eastern boundary of the area is about 40 miles west of the New Mexican border, the western, about 50 miles southeast of Tucson.

The principal mining town in the area is Tombstone, the earliest of the great Arizona camps. Though mineral production has fallen far from the spectacular figures of the eighties, it still continues more actively there than in any of the other districts in the area. Benson is an agricultural center and railroad town in the northwest part of the area; St. David, an old Mormon settlement 5 miles southeast of Benson, is the center of a small irrigated district. A dozen miles south of St. David is the hamlet of Fairbank, a minor junction point on the railroad. In the eastern part of the area are the old, nearly inactive mining towns of Pearce, Courtland, and Gleeson. Aside from these towns there are only scattered ranchhouses and railroad maintenance buildings. The principal economic activity of the region is stockraising.

Both the Bowie and Douglas routes of the main line of the Southern Pacific Lines traverse the area. The Bowie route passes through Benson in the northwest corner of the area and thence east-northeastward by way of Dragoon Pass to the north of the Dragoon Mountains. The Douglas line also passes near Benson but 400 feet higher than the Bowie line. It turns southeastward to Fairbank, where it crosses the San Pedro River and follows the river southward, swinging east again only after reaching the south end of the Mule Mountains, 10 miles farther south. The two main lines are connected by a spur along the San Pedro River from Benson to Fairbank. From Fairbank a branch extends about 8 miles east to Tombstone. Another branch passes westward along the Babocomari River and connects Fairbank with Nogales, about 60 miles to the southwest. From Lewis Springs, another branch extends west to serve the Army post at Fort Huachuca, a few miles west of this area.

Formerly there was railroad service to Pearce, Courtland, and Gleeson. Induced by the mining activity in these districts in 1907, the Arizona Eastern Railroad and the El Paso and Southwestern Railroad raced to build their roadbeds to them. However, the moribund state of mining after 1918 led eventually to the abandonment of this trackage in 1932.

The principal highway in the area is U. S. 80, which passes through Benson, St. David, and Tombstone and thence south to the Mule Mountains, which it crosses at Mule Pass just south of this area. An alternate of

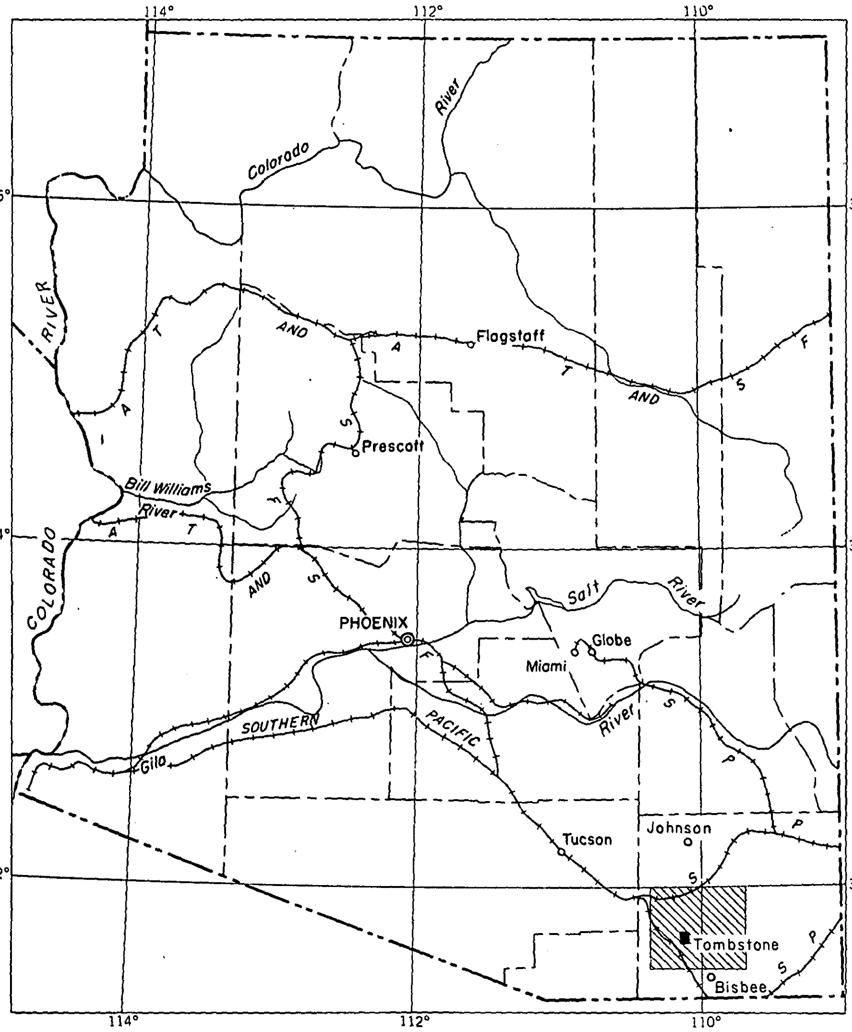

FIGURE 1.—Index map showing area of this survey.

this route goes directly east from Benson, paralleling the Bowie line of the railroad and passing north of Dragoon Pass. Other improved highways connect Tombstone with Pearce, by way of Gleeson and Courtland; Tombstone with Nogales, by way of Fairbank; Pearce with Cochise to the north, and with Douglas to the south. Many unimproved but passable ranch roads give access to nearly all the rest of the region; probably a car can be driven to within 4 miles of any point in the area.

PHYSICAL FEATURES

The country covered during this survey includes parts of the San Pedro Valley on the west and Sulphur Spring Valley on the east. These two great intermontane plains are separated by highlands, the Dragoon Mountains toward the north and the Mule Mountains on the extreme south of the quadrangles. Between these two ranges the divide between the Sulphur Spring and San Pedro Valleys lies in a broadly convex upland of low local relief, dotted here and there by isolated buttes and mesas, each a few hundred feet above the surrounding plain.

The Dragoon Mountains, all but the extreme northern end of which is included in the area, form a rough serrate mass about 20 miles long that culminates in Mount Glen, 7,512 feet in altitude. The southern half of the mountains consists of a single high ridge with scattered, much lower, outlying foothills. North of Middlemarch Canyon and Gordon Camp, the range widens and becomes both higher and more rugged as well as losing its simple linear form. In part these differences from the southern half are doubtless due to the greater width of the original mountain block; in part, however, they are reflections of the much greater proportion of massive igneous rocks and associated contact rocks in the northern part of the mountains. Around the center of this roughest part of the range are

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the deep, narrow, and winding canyons that in the days of the Apache wars gave shelter to Chief Cochise and his warriors—Cochise Stronghold.

The narrow southern part of the mountains is crossed by two passes: Middlemarch Canyon and South Pass, both of which are traversed by roads, although that through South Pass is no longer passable by automobile.

East and southeast of South Pass is a chain of hills trending roughly north from Gleeson and separated from the main ridge to the west by a sloping dissected rock plain about 2 miles wide. These hills include the Gleeson Ridge, Turquoise Ridge, and other lower hills, and in them are the mining camps of Gleeson and Courtland.

The Dragoon Mountains terminate southward near the latitude of Gleeson. Low hills rising above broad rock-cut and alluvial plains occupy the whole belt of country extending from Gleeson and the Cowan Ranch on the east to Lewis Springs and the flag station of Brookline on the west. These hills include Sugarloaf Hill, Hay Mountain, Stockton Hill and many less prominent unnamed hills on the east; the Tombstone Hills in the middle of the belt; and the Charleston Hills and other lower ones on the west. None exceed 5,600 feet, and most are less than 5,000 feet in altitude.

South of this belt of low relief, and more or less arbitrarily divided from it by Government Draw, is the northwest end of the Mule Mountains. Government Butte, the east-trending ridge near the center of T. 21 S., R. 23 E., may be regarded as the northwest end of the Mule Mountains. This range widens to the east and south and is about 10 miles wide where it is crossed by the south boundary of the quadrangles. It extends about 10 miles farther south, almost to the Mexican border. The high point of the Mule Mountains, near the southern boundary, in the area of this report is 6,669 feet; but in the Bisbee quadrangle to the south, altitudes of 7,300 feet are reached.

The western part of the map area is occupied by a segment of the San Pedro Valley—a great intermontane depression that extends from northern Sonora for about 150 miles to a point beyond Kelvin, more than 100 miles north-northwest of Benson. In this latitude the San Pedro Valley is bounded on the east by the Dragoon and Mule Mountains and on the west by the Whetstone, Mustang, and Huachuca Mountains, beyond the western limits of the mapped area. The axis of the San Pedro Valley is remarkably straight throughout its length despite the rather irregular disposition of the bordering mountains. It is drained by one of the few perennial streams of southern Arizona, the San Pedro River, a tributary of the Gila, which it joins at Winkleman, about 100 miles north of Benson.

In this area the San Pedro Valley averages about 20 miles in width. It is a broad, open trough within which the low hills between Boquillas and Lewis Springs and the Tombstone Hills form the only conspicuous landmarks. From the axial stream, along which an inner valley about 3 miles wide has been opened at the latitude of Benson, the general surface of the trough rises in gently sloping terraces, the gradients of which increase toward the bordering mountains on either hand. South of St. David the inner valley has not been greatly widened and forms a narrow trench that extends upstream to the vicinity of Lewis Springs. The bordering pediments in the vicinity of Fairbank form two steps in the valley profile, but south of Lewis Springs only one surface is noteworthy. North of Lewis Springs these smoothly sloping surfaces, despite the impression of a monotonous plain that they give on distant view, are everywhere highly dissected by narrow gulches to depths of 100 feet or more. These features and their origin are more fully discussed in the section of this report dealing with physiography.

The Sulphur Spring Valley, on the east of the map area, is another huge intermontane plain comparable to the San Pedro Valley. From the divide with Arivaipa Creek, about 50 miles north-northwest of Pearce, the valley extends southward through this area and on into Sonora. In the latitude of Courtland the valley is about 10 miles across but it widens both to the north and south, being 30 miles wide in the latitude of Pearce and about 18 miles wide east of the Mule Mountains. (Only 8 to 15 miles of this width is included in the accompanying map.) East of the map area the valley is bounded by the Chiricahua Mountains and the Swisshelm Mountains, a lower western spur of the Chiricahuas.

The floor of Sulphur Spring Valley is a smooth plain, with only a few low hills and mesas dotting its surface near, and east of, Pearce. These hills, apparently scattered in the area of the map, appear on broader view to be roughly alined on northwest trends. They are apparently pinnacles of a northwesterly extension of the Swisshelm Mountains that are almost buried by alluvium. South of these hills most of the Sulphur Spring Valley is drained by Whitewater Draw, which flows south to join the San Bernardino River and eventually the Yaqui in Sonora. North of the hills the drainage goes to the Willcox Playa, a desert sink with no external flow. Despite these differences in drainage regimen, both parts of the valley have nearly the same topography, and both are broadly concave with their sides slightly scored by shallow drainage courses but with none of the terraced topography that is so striking a feature of the San Pedro Valley.

In the northern part of the San Pedro Valley near St. David, the mountains and hills on the west are in general closer to the stream and steeper than those on the east, a condition opposite to that from the latitude of Fairbank southward. The terraces bordering the inner valley near St. David rise toward the Dragoon Mountains on the east at about 100 feet per mile; toward the Whetstone Mountains on the west the rise is nearly twice as steep. A possible explanation for this difference in slope is the shorter distance to high mountains on the west; another factor may be the differences in the bedrocks of the two ranges—the granitic rocks of the northern Dragoon Mountains supplied finer detritus to the streams than the Paleozoic rocks of the Whetstone Mountains.

The lowest point in the area is on the San Pedro River where it leaves the quadrangle north of Benson, at somewhat below 3,500 feet. The San Pedro River at the south boundary of the area is flowing at about 4,080 feet and thus falls about 600 feet in 35 miles.

There is no such marked asymmetry of the alluvial slopes of the Sulphur Spring Valley. This valley rises from about 4,050 feet where Whitewater Creek leaves the area to a little over 4,300 feet between Turkey Creek Ridge and Township Butte, a slope of only about 10 feet per mile. Northward toward the Willcox Playa the descent is at about the same gradient.

The mountains and most of the lower hills throughout the area rise abruptly from these gently sloping plans, but the local relief only in a few places exceeds 1,000 feet per mile. The total relief is a trifle more than 4,000 feet, from the lowest point on the San Pedro River to the summit of Mount Glen at 7,512 feet.

CLIMATE AND VEGETATION

The climate of the region is dry. The precipitation varies with the altitude, ranging from about 10 inches a year at Benson (elevation 3,523 feet) in the San Pedro Valley to over 19 inches at Bisbee (elevation 5,425 feet) in the Mule Mountains. Probably 20 inches is exceeded on some of the higher mountains. Over one-half the total annual rainfall is largely concentrated in the months of July, August, and September. A minor secondary maximum occurs in the winter, but the most pronounced feature is probably the marked drought that occurs in April, May, and June. The accompanying tables summarize the information available up to 1930 from United States Weather Bureau reports for points in and near the area.

Average precipitation in inches (to 1930) at points in and near the area

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Elevation in feet
Allaires Ranch (Willcox Playa)	0.71	0.82	0.73	0.20	0.15	0.28	2.62	2.60	1.37	0.57	0.79	0.71	11.55	4,184
Apache Powder Co. (St. David)	.33	.46	.73	.45	.28	.38	2.80	2.48	2.07	.59	.66	.70	11.93	3,690
Benson	.57	.67	.54	.18	.12	.29	2.48	2.33	1.21	.62	.51	.60	10.12	3,523
Bisbee	1.17	1.25	1.08	.51	.28	.56	4.37	4.58	1.90	1.11	.96	1.31	19.08	5,425
Bowie	.91	1.32	.97	.21	.26	.44	2.67	2.57	1.08	.65	.66	1.00	12.74	3,756
Cochise	.87	.93	.63	.23	.27	.23	2.87	2.38	1.26	.66	.69	.82	11.84	4,250
Douglas	.79	.75	.65	.28	.26	.40	3.55	2.99	1.39	.99	.79	.87	13.71	3,939
Fort Huachuca	1.32	1.19	.95	.28	.30	.52	3.81	4.02	1.82	.69	.94	1.12	16.96	5,100
Hereford	.66	.34	.61	.22	.14	.45	3.82	2.88	1.48	.64	.62	.77	12.63	4,180
Lewis Springs	.50	.58	.37	.14	.14	.62	3.28	2.62	1.12	.56	.63	.59	11.15	4,029
Naco	.69	.61	.68	.29	.17	.58	4.12	2.73	1.54	.79	.80	1.04	14.04	4,579
Tombstone	.82	.86	.76	.32	.27	.48	3.66	3.41	1.67	.72	.73	.86	14.56	4,580
Willcox (near)	.85	.89	.80	.16	.26	.25	2.33	2.44	1.05	.66	.70	.82	11.21	4,200

Temperatures are generally mild in winter but very high in summer. Extreme maximums of 115° have been noted at Bowie, and temperatures in excess of 100° are common; however, the nights are generally cool. The accompanying table summarizes some of the temperature data for points in and near the area.

Recorded temperatures in degrees Fahrenheit (to 1930) at points in and near the area

Station	Annual average	Average maximum	Average minimum	Extreme maximum	Extreme minimum
Benson	64.3	80.0	44.8	110	5
Bisbee	61.0	73.3	48.9	106	8
Bowie	63.3	81.3	46.9	115	10
Cochise	61.0	76.8	43.3	114	−6
Cochise Stronghold	60.8				
Douglas	62.4	78.9	45.8	111	−7
Fort Huachuca	61.4	74.9	48.0	105	0
Tombstone	62.7	76.4	49.0	110	9
Willcox	59.6	76.0	40.3	110	2

The natural vegetation differs greatly with the altitude and availability of water. The higher mountains support a scattered growth of yellow pine which gives way at lower altitudes to juniper, live oaks, and cedars. Along stream courses, cottonwoods and live oaks are common.

On the lower mountain slopes and upper alluvial fans, the principal vegetation includes Yucca, Spanish-bayonet, sotol, creosote bush, hackberry, cholla, catclaw, and ocotillo. Grasses formerly flourished on the higher pediments and on the lower slopes of the valleys, but the natural pasturage has been greatly reduced in recent years. It is said that grama grass stood "stirrup-high" over most of the Sulphur Spring Valley and Government Draw before the advent of the great cattle herds in the 1880's, but the present grass cover is very patchy and consists largely of isolated small clumps. In the lower country mesquite is probably the most conspicuous shrub and furnishes a large part of the forage for the cattle ranges. Sagebrush is found on some of the sandy patches on the eastern side of Sulphur Spring Valley, and in a few of the more alkaline spots saltgrass and shadscale are conspicuous.

FIELDWORK

The fieldwork upon which this report is based began in November 1936. Many interruptions occurred, but the mapping was completed in August 1940 after a total of about 15 months of fieldwork. Edgar Bowles, Ralph S. Cannon, Jr., W. B. Myers, J. H. Wiese, S. C. Creasey, and F. S. Simons assisted in the survey at various times. To their ability and industry I am greatly indebted for much of the mapping and for stimulating discussions that served to clarify many puzzling questions that arose during the work.

The geologic map was made by planetable and open-sight alidade, upon a topographic base photographically enlarged to a scale of 1:62,500. Geologic sections were in part measured by planetable and stadia traverses, in part by steel tape and compass traverse, in small part by hand leveling.

SCOPE OF THE REPORT

The objective of the work was to obtain a geologic understanding of a large area that not only includes the formerly important Tombstone silver district and the much less productive and now inactive Turquoise (Courtland–Gleeson), Dragoon Camp, Middlemarch copper, and Pearce silver areas but occupies much of the interval between the great copper-lead-zinc mines of Bisbee to the south and the Johnson Camp copper-zinc district to the north. It may thus be regarded as a background study for a more intensive examination of these mining districts.

Although the work by E. D. Wilson (1927) at Courtland and Gleeson had been done more than a decade earlier, the mines were largely inactive and inaccessible even then. At the time of this survey, only one or two of the former workings were accessible, and nothing could be added to Wilson's descriptions. No study of the geology of the bonanza camp of Pearce has been published; the workings there, like those of Dragoon Camp and Middlemarch Canyon, were completely inaccessible at the time of this survey.

The area of the Tombstone Special Topographic map, which lies within the larger area covered by this report, had been mapped on a scale of 1:24,000 by F. L. Ransome and checked in the vicinity of the mines by B. S. Butler, Eldred D. Wilson, and C. A. Rasor (1938, pl. 3). Accordingly, only as much work was done in this area as was necessary to reconcile the geologic boundaries mapped around the borders with Mr. Ransome's boundaries. In the vicinity of the mines, Mr. Ransome's boundaries were so accurate in the many places where checked by later work that no attempt was made to go over his mapping in detail. The only additional work done here was to subdivide the Naco formation as mapped by him into the several formations recognized elsewhere in the area.

ACKNOWLEDGMENTS

During the spring of 1937, J. B. Reeside, Jr., visited the area and assisted greatly both by skillful collecting and interpretations of lithology in the work on the stratigraphy of the Comanche rocks. At the same time, S. G. Lasky offered helpful comments on the volcanic rocks southwest of Tombstone. During the summer of 1938, Josiah Bridge and Wilbert Hass spent 2 weeks in collecting, largely in company with Mr. Cannon and me, from the sections of early Paleozoic age of this and nearby areas. James Steele Williams also spent about 2 weeks in fossil collecting and other stratigraphic work on the formations of Carboniferous age. Without his counsel the interpretation of this part of the section would have suffered greatly. In 1947 Williams and J. R. Cooper, who was mapping the Dragoon quadrangle which adjoins this area on the north, again spent several days in going over the stratigraphy in the field.

J. H. Macia, of Tombstone, and Edward Kelley, of Pearce, familiar for nearly 40 years with the mining industry of the region, furnished a great deal of helpful information. To them and other residents of the area, grateful acknowledgments for courtesies and help are tendered.

PRINCIPAL GEOLOGIC FEATURES

The rocks exposed in the area range in age from pre-Cambrian to Recent and embrace a wide lithologic variety. The pre-Cambrian is represented by schist and presumably by albite granite, quartz diorite, gneissic granite, and saussuritic quartz monzonite, though the age of some of the plutonic bodies is uncertain. The Paleozoic era is represented by quartzite, shale, limestone, and dolomite of Cambrian age aggregating about 1,300 feet in thickness; by about 300 feet of limestone and shale of Devonian age; and by about 4,000 feet of limestone, dolomite, and subordinate clastic rocks of Carboniferous and Permian ages. Rocks of Mesozoic age include two varieties of granite, two of quartz monzonite, and a monzonite porphyry, all of pre-Cretaceous age; andesitic volcanics; and conglomerate, shale, sandstone, and limestone of Comanche age as much as 15,000 feet thick. Of uncertain age, either Late Cretaceous or early Tertiary, are andesitic volcanic rocks 5,000–6,000 feet thick, quartz latite flows and related pyroclastic rocks at least 1,500 feet thick, and two small masses of granite. Rocks of probable Tertiary age include quartz latite porphyry, andesite porphyry, granodiorite, granite, rhyolite porphyry, quartz monzonite porphyry, and a wide variety of dike rocks; rhyolitic pyroclastic rocks aggregating at least 1,600 feet in thickness; hornblende andesites 1,000 feet thick; quartz latite tuffs and lavas 1,100 feet thick; and fanglomerate, sandstone and mudstone at least 700 feet thick. The Quaternary rocks include fanglomerate, fluviatile sandstone, silt and clay, and lacustrine marlstones, as well as small amounts of stream gravels and dune sands. The combined maximum thickness of supracrustal rocks in the area is thus about 33,000 feet, or more than 6 miles. They have been subdivided for mapping purposes into 26 units—in addition, 20 intrusive units, one tectonic unit, and the pre-Cambrian schist have been distinguished.

The geologic structure is complex and highly different from place to place. The pre-Cambrian structural features are largely indecipherable; a northeastward trend of the schistosity imposed at this time is suggested but not proved. Folding of post-Paleozoic–pre-Comanche age, probably along northerly axes, is demonstrable in the Mule Mountains and in the northern Dragoon Mountains. Folding of post-Comanche age has also occurred: along northwest axes in the Mule Mountains, along east axes at the extreme northern end of the Mule Mountains and in the intervening country as far north as the Tombstone Hills, and along north-northwest axes in the Dragoon Mountains and the foothills to the east of them. Thrust faults trending east are found in the northern Mule Mountains. A few thrust remnants and local overturning along northwest lines attest the thrusting in the Tombstone area, and thrusting of north to northwest trend and easterly displacement of the overriding blocks is prominent in the Dragoon Mountains. In all these areas there is a close association of many folds with the thrusts, but in the Tombstone Hills and farther south the folds are partly, at least, independent of the faults. Lack of fossils of ages intermediate between Comanche and Pliocene has prevented accurate dating of these orogenic events, and they have been arbitrarily assigned to the Late Cretaceous or early Tertiary. Of considerably later time are the slight doming of the older structure features over the Stronghold granite in the northern Dragoon Mountains and the tilting, folding, and faulting of the younger volcanic and sedimentary rocks. Locally the faulting has persisted later than the deposition of the Gila conglomerate, and it is probable that most of the mountains and hills have been differentiated from the valley lands by normal faults of the Basin and Range type, although such faults can be definitely established only along the west side of the southern Dragoon Mountains. It is inferred that faulting as young as Pleistocene has been negligible or absent.

The mineralization of the Tombstone, Courtland, and Gleeson districts is probably of middle Tertiary age; that of the Pearce district may be somewhat younger.

During Pleistocene time the Tertiary and other rocks of the San Pedro and Sulphur Spring troughs were planed, and broad pediments formed. Two cycles may be readily recognized in the erosional history of the San Pedro trough. In late Pleistocene time the northern part of the Sulphur Spring Valley was occupied by a permanent lake instead of by the widely fluctuating playa of the present. During Recent time the Pleistocene surfaces of the San Pedro Valley have been deeply dissected. In the Sulphur Spring Valley the absence of external drainage from the northern part and the feebleness of Whitewater Draw combined with distance from strong through-flowing streams have prevented similar dissection.

The following table summarizes the sequence of rock formations in the various parts of the area.

Summary of sequence

Age			Tombstone Hills	Mule Mountains	Southern Dragoon Mountains
Quaternary			Alluvial deposits. —Unconformity— Basalt, intrusive.	Alluvial deposits. —Unconformity—	Alluvial deposits. —Unconformity— Basalt flows; 20 feet.
Tertiary	Pliocene		Gila conglomerate: conglomerate, sandstone, silt, clay; several hundred feet. —Unconformity—	Not recognized.	Gila conglomerate: conglomerate, sandstone; several hundred feet. —Unconformity—
Tertiary	Eocene(?) to lower Pliocene		Rhyolite dikes, plugs, sills. —Intrusive contact— Sandstone, conglomerate, mudstone; 80 feet. —Unconformity— Schieffelin granodiorite: quartz-poor granodiorite to quartz monzonite. Andesite porphyry dikes. Uncle Sam porphyry: quartz latite porphyry to quartz monzonite porphyry. —Intrusive contact—	Rhyolite dikes, plugs, sills. —Intrusive contact— Not recognized.	Andesite, intrusive. S O volcanics: 500–3,600 feet. Upper member; quartz latite tuffs and flows; 1,100 feet. Middle member; hornblende andesite flows; 300–1,000 feet. Lower member; rhyolitic tuff, obsidian, tuff-breccia; up to 1,600 feet. —Unconformity— Conglomerate, sandstone, silts, claystone; 200 feet. —Unconformity— Quartz porphyry dikes, probably related to the Stronghold granite. —Intrusive contact—
Upper Cretaceous or lower Tertiary			Bronco volcanics: Upper member; quartz latite and quartz latite tuff; 2,500 feet. Lower member; felsophyric andesite flows and flow breccia; 3,500 feet. —Unconformity—	Not recognized.	Sugarloaf quartz latite: biotite quartz latite and biotite quartz latite tuff; feldspathic andesite flows and breccia; 1,500 feet. —Unconformity—
Cretaceous	Comanche series		Bisbee formation: conglomerate, sandstone, mudstone; at base a little limestone; 3,000 feet. —Unconformity—	Bisbee group: Cintura formation; sandstone, mudstone, a few thin limestone beds; 1,800 feet. Mural limestone; reef limestone, thin-bedded limestone, a little shale; 650 feet. Morita formation; sandstone, mudstone, a few thin limestone beds; 3,000 feet. Glance conglomerate; conglomerate; up to 100 feet. —Unconformity—	Bisbee formation: sandstone, mudstone, a little limestone; conglomerate; several hundred feet; much faulted. Andesitic volcanic rocks near South Pass. —Unconformity—
Triassic or Jurassic			Not recognized.	Juniper Flat granite: granite to granite porphyry. —Intrusive contact—	Turquoise granite: highly sericitic, silicified granite. Gleeson quartz monzonite: much sheared, altered quartz monzonite and alaskite. Copper Belle monzonite porphyry: quartz-poor, saussuritic monzonite porphyry. —Intrusive contact—
Permian (?) and Permian		Naco group	Epitaph dolomite: dolomite, sandstone, limestone; 780 feet. (Probably of Leonard age.)	Not exposed.	Epitaph dolomite: dolomite, in thin fault slices only, a few score feet thick.
Permian (?) and Permian		Naco group	Colina limestone: limestone, chiefly dark gray, aphanitic; 635 feet (of Wolfcamp and Leonard age).	Colina limestone: limestone, chiefly dark-gray, dense; a few hundred feet.	Colina limestone: limestone, chiefly dark-gray, aphanitic; a few score feet, faulted.
Pennsylvanian	Upper	Naco group	Earp formation: limestone, shale, limestone conglomerate, and thin dolomite beds; 595 feet.	Earp formation: limestone, shale, limestone conglomerate, and thin dolomite beds; several hundred feet.	Earp formation: limestone, shale, thin dolomite beds; faulted; several scores of feet thick.
Pennsylvanian	Lower	Naco group	Horquilla limestone: limestone, chiefly light-gray or pink, aphanitic, a few crinoidal beds; 1,000–1,200 feet. (In places upper Pennsylvanian at top.)	Horquilla limestone: limestone, chiefly light-gray or pink, aphanitic, a few crinoidal beds; several hundred feet.	Horquilla limestone: limestone, chiefly light-gray or pink, aphanitic; a few crinoidal beds; several hundred feet.
Mississippian	Lower		Escabrosa limestone: massive, crinoidal limestone; 786 feet. (May include upper Mississippian locally.)	Escabrosa limestone: massive, crinoidal limestone; several hundred feet.	Escabrosa limestone: massive, crinoidal limestone; several hundred feet.
Devonian	Upper		Martin limestone: limestone, shale, sandstone, a little chert; 230 feet.	Martin limestone: limestone, shale, sandstone; 340 feet.	Martin limestone: limestone, shale, sandstone; faulted, a few score feet.
Cambrian	Upper		Abrigo limestone: limestone, limestone mottled with shale, shale, a little quartzite; 844 feet.	Abrigo limestone: limestone, mottled with shale; shale; a little quartzite; 770 feet.	Abrigo limestone: limestone, shale, edgewise conglomerate, sandstone; 636 feet.
Cambrian	Middle		Bolsa quartzite: quartzite, grit, and conglomerate; 440 feet. —Unconformity—	Bolsa quartzite: quartzite, grit, conglomerate; 430 feet. —Unconformity—	Bolsa quartzite: quartzite, grit, conglomerate; 300 feet. —Unconformity—
Pre-Cambrian			Albite granite. —Intrusive contact— Pinal schist: muscovite, chlorite, quartz schist, minor amphibolite.	Quartz diorite. —Intrusive contact— Pinal schist: muscovite, chlorite, quartz schist, minor amphibolite.	Gneissic granite. —Intrusive contact— Pinal schist: muscovite, chlorite, quartz schist, minor amphibolite.

of rock formations

Northern Dragoon Mountains	Sulphur Spring Valley	Remarks
Alluvial deposits.	Alluvial deposits.	Quaternary deposits not distinguished in mapping from Gila conglomerate.
———Unconformity———	———Unconformity———	
	Gila conglomerate: conglomerate, sandstone, siltstone; a few score feet exposed.	
———Unconformity———	———Unconformity———	
Not recognized.	Pearce volcanics: 2,650 feet; chiefly rhyolite and rhyolite tuff, with olivine andesite and hornblende andesite.	Owing to mineralogical differences, Pearce and S O volcanics cannot be congenetic; wide areal separation prevents determination of their relative age.
	———Unconformity———	
Stronghold granite: granite to quartz monzonite.	Quartz porphyry dikes, probably related to the Stronghold granite.	Petrographic differences between Stronghold granite and Tombstone Hills intrusions do not favor correlation. All these intrusions are younger than the thrust faults.
———Intrusive contact———	———Intrusive contact———	
Granite gneiss near Jordan and Fourr Canyons.	Granite in Ash Creek Ridge.	Major epoch of thrust faults. Petrographic differences between the Bronco volcanics and Sugarloaf quartz latite make correlation improbable; relations of the two intrusive masses to these volcanic rocks unknown.
———Intrusive contact———	———Intrusive contact———	
Bisbee formation: sandstone, mudstone, and conglomerate several hundred feet	Bisbee formation: sandstone, mudstone, conglomerate, and a few thin limestone beds; 16,000 feet.	Northward wedging-out of the Mural limestone and similarity of Morita and Cintura formations prevents recognition of Mule Mountains subdivisions elsewhere in the area.
———Unconformity———	———Unconformity———	
Cochise Peak quartz monzonite: porphyritic quartz monzonite, much altered, sheared, and in part metamorphosed.	Not recognized.	Mutual relations of these intrusive masses not known, all recognized contacts between them are faults.
———Intrusive contact———		
Epitaph dolomite: dolomite, sandstone, limestone; several hundred feet.	Not exposed.	
Colina limestone: limestone, chiefly dark-gray, dense; several hundred feet.	Not exposed.	
Earp formation: limestone, shale, limestone conglomerate, thin dolomite beds; several hundred feet.	Not exposed.	In faulted areas, Earp commonly much thinned by shearing out of shaly beds.
Horquilla limestone: limestone, chiefly light-gray or pink, aphanitic; several hundred feet.	Horquilla limestone: several scores of feet exposed.	
Escabrosa limestone: massive, crinoidal limestone; several hundred feet.	Escabrosa limestone: several scores of feet exposed.	
Martin limestone: limestone, shale, sandstone, a little chert; several scores of feet.	Not exposed.	In faulted areas, Martin commonly sheared out and unrecognizable.
Abrigo limestone: limestone, mottled with shale, shale, a little quartzite; several hundred feet.	Not exposed.	
Bolsa quartzite: quartzite, grit, and conglomerate: several hundred feet.	Not exposed.	
———Unconformity———		
Saussuritic quartz diorite.		
———Intrusive contact———		
Pinal schist: muscovite, chlorite, quartz schist, andalusite-mica schist, a little amphibolite.	Not exposed.	In areas of intense metamorphism, distinguished with difficulty from metamorphosed Bisbee formation.

PRE-CAMBRIAN ROCKS

PINAL SCHIST

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

Schists that indubitably belong to the formation classed by Ransome (1904, p. 24) as Pinal in the Bisbee district crop out in five principal areas in the region of this survey. These are (1) an area of about 2½ square miles along the west flank of the Dragoon Mountains north of South Pass, (2) an area of about a quarter of a square mile on the west slope of Ajax Hill in the Tombstone district, (3) an area of about 2 square miles at Sandy Bob Ranch, just east of Highway 80 at the south edge of the area; (4) an elongate area of about half a square mile south of the Stronghold School east of Cochise Stronghold, and (5) an area of about 1½ square miles in and near Jordan Canyon at the northern end of the Dragoon Mountains. Smaller bodies of undoubted Pinal schist also occur as thrust slices in the intricately faulted region between Sugarloaf Hill, south of Gleeson, and the north end of Turquoise Ridge, a mile northwest of Courtland; in the western foothills of the Dragoon Mountains about a mile south of the Fourr Ranch; on the northwest spur of Black Diamond Peak, in the main ridge of the Dragoon Mountains; and near Middlemarch.

Many other bodies of schist have been referred to the Pinal on less certain grounds. In many places the Bisbee formation has been metamorphosed to schists that superficially resemble the Pinal very closely, and it is possible that some of the masses mapped as Pinal on plate 5 should have been assigned to the Bisbee. Among these may be mentioned the areas of schist shown as Pinal: 1, north and south of China Peak, where the schist forms a roof pendant or reentrant in the Stronghold granite;[1] 2, on the south slope of Black Diamond Peak; and 3, the many inclusions in the Gleeson quartz monzonite between Signal Hill, the Bar-O Ranch house (2 miles south of South Pass), and Gleeson. Some of the rocks in these doubtful areas are lithologically identical with undoubted Pinal, but others are altered to hornfels or injection gneiss whose antecedents cannot be so confidently inferred. Some of them show, under the microscope, residual clastic textures that suggest derivation from a previously unmetamorphosed rock. Hence, some of these rocks may be post-Pinal, though Ransome (1919, p. 35), in the Ray district, has described undoubted Pinal schist that retain such clastic textures.

In all these areas the Pinal schist forms relatively subdued topography. Ordinarily its exposures are very poor, owing to its surficial disintegration into small flaky and laminated chips. Its exposures on steep hills are limited to slopes capped by resistant ledges, such as the Glance conglomerate or Bolsa quartzite, whose durability prevents rapid erosion and permits the stripping of the weathered debris from the slopes below.

The Pinal weathers to a somber brown or greenish brown that, in conjunction with its characteristic topographic forms, commonly permits its ready discrimination from all the other formations of the area except the Bisbee formation where that formation has been intensely metamorphosed.

THICKNESS

As the base on which the Pinal was deposited is exposed nowhere in the area and the structural complexities are great, there is no possibility of obtaining any worthwhile estimate of the thickness of the formation. However, it is likely that the Pinal is thousands of feet thick—otherwise the base would be somewhere exposed, for the bedding, where recognizable, commonly stands at high angles.

PETROGRAPHY

The principal rocks of the Pinal schist are muscovite-quartz schists, chlorite-muscovite-quartz schists, chlorite-oligoclase-microcline-quartz schists and chlorite-albite-quartz schists. Prominent minor facies are amphibolites, which include oligoclase-epidote-chloritized-hornblende schists and saussurite-actinolite gneiss. Near many of the younger intrusive masses rocks of all these facies have been changed to hornfels.

For the most part, these rocks are thinly laminated, except for the amphibolites, which are commonly phacoidal. Inasmuch as the thin lamination of the rocks permits their ready disintegration, exposures are generally poor, but the foliation apparently is commonly closely plicated, and its attitude changes rapidly from place to place. Thus, many of the rocks are pencil schists. Locally, as near Sandy Bob Ranch, there are ptygmatic veins of pegmatite in the schists, but lit-par-lit injection was observed on only a small scale.

The dominant rocks of the Pinal are the muscovite-quartz schists and chlorite-muscovite-quartz schists. Some contain considerable oligoclase or albite, others little or no plagioclase. In some specimens from inclusions in the Gleeson quartz monzonite and the altered zones near this intrusion, the plagioclase is saussuritized and consists of aggregates of zoisite and albite, which may contain up to large amounts of sericite or none at all. Orthoclase and microcline are sporadically present and locally make up as much as 30 percent of the rock, which is there more gneissic than schistose, but these minerals are everywhere subordinate to quartz. Biotite is found in small amounts and is perhaps more than normally abundant in the Pinal near Black Diamond

[1] These masses have been referred to as "Mesozoic shale and sandstone" (equivalent to the Bisbee formation of this report) by D. J. Cederstrom (1946, p. 601–621).

Peak and Cochise Peak, where the schist has been contact-altered by younger intrusions; even here, however, the mica has largely been altered to chlorite.

Minor parts of the Pinal are composed of altered igneous rocks—apparently sills of basalt or andesite that are now phacoidal amphibolite. These rocks consist of hornblende or actinolite, aggregates of zoisite and oligoclase, a little quartz, orthoclase, and accessories such as apatite and magnetite; some have also either biotite or chlorite or both. One of these amphibolite bodies included in the Gleeson quartz monzonite west of Gleeson retains some augite poikilitically enclosed in the hornblende. Another, from a point half a mile north of South Pass, consists of actinolite, epidote, saussurite, and a little calcite. A greenstone northwest of Cochise Peak consists of augite, which is only in part altered to hornblende and chlorite, andesine, orthoclase, a little quartz, and a few flakes of biotite. Another from the same locality contains blue-green hornblende, epidote, and oligoclase. Doubtless, all these rocks are metamorphosed basalts or andesites.

Near younger intrusions the Pinal has commonly been altered to knotted schist or even massive hornfels. Along Turquoise Ridge the knots, which were presumably either cordierite or andalusite, are now represented by "pinitic" aggregates of muscovite; rocks which have been similarly altered from Black Diamond Peak and west of Cochise Peak retain kernels of andalusite in the midst of the pinite pseudomorphs. Tourmaline, though it is accessory in most specimens of the Pinal, is especially abundant in these hornfels specimens and the neighboring knotted schists.

The texture of most of the schists is crystalloblastic, though some show becciation and a few from the west side of Brown's Peak, though wholly crystalloblastic, retain what appear to be relicts of an original sedimentary texture. The thinner laminated members are characterized by strong parallel textures, but some of the more massive members, and particularly the greenstones, are rather granoblastic, though commonly showing later crushing.

ORIGIN

The detailed studies of Ransome (1919, p. 35–37) have shown that the Pinal schist in the type locality in the Pinal Mountains consists of metamorphosed sedimentary rocks with minor intercalations of volcanic rocks. The same origin is indicated in the area of this report; most of the rocks are highly quartzose, relatively poor in feldspar, and the less-quartzose facies are very rich in muscovite and chlorite. These features are to be expected in altered sedimentary rocks, and the fine lamination of nearly all the rocks other than the amphibolites also strongly suggests a sedimentary derivation. The amphibolites are doubtless altered sills and flows of basaltic composition.

The cause of the original metamorphism of the Pinal schist cannot be determined. The close plication of the rocks suggests that orogenic disturbances may have caused the metamorphism. The only visible intrusive masses old enough to have brought about the metamorphism are small. Furthermore, the metamorphic grade of the Pinal is not noticeably higher near these bodies than elsewhere, contrary to the relations noted by Ransome (1919, p. 35–37) in the Pinal Mountains. All the large intrusive masses of this area are younger than the formation of the schistosity of the Pinal and near them the foliation is masked by hornfels textures, as is to be seen both in the southern and northern parts of the Dragoon Mountains. Except locally, where andalusite-biotite hornfels has been formed, the principal effect of these post-Paleozoic intrusions has been the hydrothermal alteration of the older, higher grade schists. The widespread chlorite of many of the amphibolitic specimens has obviously veined and replaced the preexistent hornblende and augite, and much of the muscovite of the feldspathic rocks and all the epidote and zoisite are clearly formed from older feldspar. These changes are probably referable to hydrothermal solutions given off or set in motion by these younger intrusions. Certainly the brecciation which the rocks almost universally show seems to have been far too mild to enable this retrograde metamorphism to be referred wholly to deformation in a shallow zone in the crust.

AGE AND CORRELATION

The great difference in metamorphism and structure between the Pinal schist and the overlying Bolsa quartzite, together with the smoothly planed surface of unconformity separating them, is convincing evidence of a pre-Cambrian age for the Pinal schist and its original metamorphism.

The correlation with the type Pinal schist is based solely upon the similar lithology and age of the two formations. Owing to the discontinuous outcrops, it is impossible to trace one formation into the other.

INTRUSIVE ROCKS

HORNBLENDE-QUARTZ DIORITE

DISTRIBUTION

Two small masses of hornblende-quartz diorite crop out about half a mile northwest of Sandy Bob Ranch, about 1½ miles north-northwest of the southeast corner of the Benson quadrangle. The larger of these bodies is definitely intrusive into the Pinal schist and is bounded on the west by the Juniper Flat granite (Triassic?). This younger granite bounds the smaller mass on three sides or, perhaps better, separates the two masses of quartz diorite by a dike about 100 feet wide, concealed toward the north by alluvium. The larger of the quartz diorite masses is only about 1,500 feet long.

GEOLOGICAL RELATIONS

The contact between the Pinal schist and the hornblende-quartz diorite is an injection zone. The Pinal, for several feet normal to the contact, has been altered to an injection gneiss, with prominent augen structure and coarsening of the mica plates. Some dikes of the quartz diorite a foot or so thick penetrate the Pinal for several hundred feet. Nevertheless, the boundary between schist and intrusion can everywhere be placed within a few score feet.

The contact of the Juniper Flat granite against this quartz diorite mass is clean cut and knife sharp. Inclusions of the quartz diorite are numerous in the Juniper Flat granite, and dikes of the granite cut the quartz diorite as well as the adjacent schist.

The quartz diorite weathers into rounded forms on a subdued topography. It is apparently less resistant to erosion than the Juniper Flat granite.

PETROGRAPHY

In hand specimen, the quartz diorite shows a crudely gneissoid banding. It is dark gray, with prominent round to angular phenocrysts of white plagioclase in a groundmass of hornblende, chlorite, and feldspar. The phenocrysts attain 1 centimeter in length; the hornblende grains are somewhat smaller on the average and are only exceptionally more than 5 millimeters long. The crystals of the groundmass average perhaps a quarter of a millimeter in length. Epidote is conspicuous along joints.

Thin sections show the rock to consist of andesine, quartz, and hornblende (altered in part to chlorite and epidote) as the dominant minerals. Accessories are sphene, magnetite, and apatite. The plagioclase is in part sericitized and epidotized, and a little calcite also is present. The texture is the normal granitic but shows some small crush effects even in the quartz.

AGE

The quartz diorite is definitely older than the Juniper Flat granite that cuts it cleanly. The Juniper Flat granite is post-Permian and pre-Comanche in age. (See p. 55.) The pre-Cambrian age of the quartz diorite is not demonstrable from relations to the Bolsa quartzite. The absence of dikes in the Bolsa, despite their considerable extent in the Pinal schist; the lit-par-lit injection of the Pinal by the quartz diorite; and the clean-cutting dikes of the Juniper Flat granite in the schist suggest, however, that the two plutonics belong to different igneous cycles. The gneissic banding of the quartz diorite in this locality, even though the texture is only slightly cataclastic, also may be thought to favor its pre-Cambrian age. It is true that some gneissoid intrusive masses in the northern Dragoon Mountains are definitely younger than Comanche, but the nearby Comanche rocks in the Mule Mountains are practically unmetamorphosed.

ALBITE GRANITE WEST OF AJAX HILL, TOMBSTONE

A granitic intrusive body is poorly exposed in the Tombstone district, just west of Ajax Hill.[2] As mapped by Ransome this mass is about 1½ miles long. Butler and Wilson and Rasor (1938, p. 13) point out that its relation to the Cambrian rocks has not been proved and suggest that the contact is a fault. However, no dikes of this rock are known in the post-Pinal rocks of the area, and it is intimately associated with the Pinal schist. Petrographically the rock seems notably distinct from the nearby Schieffelin granodiorite of Tertiary age so that Ransome's classification of the mass as pre-Cambrian is here adopted.

Exposures of the rock are poor, owing to talus from the Bolsa quartzite, and fresh material for study is not readily available. The freshest specimens seen are pinkish gray, equigranular except for poikilitic orthoclase phenocrysts as much as 2 centimeters across, and of slightly gneissoid habit. Plagioclase crystals 4 millimeters long and chlorite plates 2 millimeters long are recognizable, along with quartz.

Specimens examined by Butler, Wilson, and Raso (1938, p. 13) have been described by them as granodiorite, with calcic oligoclase feldspar. However, the specimens collected by me are thoroughly albitized. except for sporadic remnants of sodic oligoclase. This sodic oligoclase is so related to the muscovitic and albitic cores of the plagioclase as to suggest that it originally formed the outer sheaths of zoned crystals. The albite is largely of chessboard habit, suggesting that it is of replacement origin (Gilluly, 1933, p. 73).

The original mafic minerals of the rock are represented by chlorite. Much of the albite is cloudy with sericite, but in some parts of the rock the mica forms rather coarse plates. As is usual in such rocks, these mica aggregates are most abundant in the cores of the feldspar. Apatite and magnetite are accessory.

The texture is poikilitic, with orthoclase "flooding" the albitized plagioclase and chlorite crystals. There is locally a little graphic intergrowth of quartz and orthoclase but not much. There has been some postcrystallization shearing as shown by the slightly

[2] The mapping of this body on plate 1 is taken from a manuscript map of F. L. Ransome and has not been checked during this survey.

cataclastic texture. The texture and minerology contrast markedly with those of the Schieffelin granodiorite (see p. 103), and no petrographic evidence appears to oppose Ransome's suggestion of pre-Cambrian age for the rock.

MINOR GRANITIC MASS NORTH OF SOUTH PASS

In a thrust fault zone near the top of the western slope of the Dragoon Mountains about 1¾ miles north-northwest of South Pass, there is a small mass of granite, a few yards along. It is merely a fault sliver, associated with a little Pinal schist (both bodies too small to show on pl. 1) and intervening between the overlying block of Bolsa quartzite and the underlying Martin limestone.

The rock is dark pinkish gray, with average grains 2 or 3 millimeters in diameter. Microcline, albite-oligoclase, quartz, muscovite, and chlorite are the principal minerals. The rock is crystalloblastic-cataclastic, with mortar texture, and is a sheared gneissic granite.

Although the rock resembles some of the sheared facies of the Gleeson quartz monzonite and may belong to that formation, it also strongly resembles the quartz monzonite near Dragoon Camp, which is almost surely of pre-Cambrian age. Its structural relations and association with Pinal schist and Bolsa quartzite agree with, though they do not compel, an assignment to the pre-Cambrian.

METAGABBRO AND METADIABASE ASSOCIATED WITH PINAL SCHIST

Small bodies of metagabbro and metadiabase, most of them associated with the Pinal schist, are found at several places in the main mass of the Gleeson quartz monzonite. They appear to be inclusions in the quartz monzonite, like the adjacent schist.

None of these masses are large enough to show on the accompanying map without unwarranted exaggeration, and most are less than 20 feet in exposed width. Some of them are relatively coarse grained, with crystals of epidote up to 2 millimeters long in a feldspathic base of somewhat finer grain. Microscopic examination revealed that they consist of epidote, zoisite, chlorite, muscovite, carbonate, and albite, in a crystalloblastic texture. Inasmuch as the primary feldspar has been completely destroyed, the classification of the original rock is uncertain, but the abundance of dark minerals makes it seem likely that the original rock was a gabbro. Other of the rocks are less thoroughly recrystallized and contain recognizable ophitic textures, though they have been somewhat sheared and the feldspar is largely saussuritic. These contain hornblende, chlorite, magnetite, muscovite, and feldspar, which, though saussuritic, is approximately An_{50} in composition. The rocks are probably metadiabase.

Assignment of these rocks to the pre-Cambrian is of course uncertain. All that can be said with assurance is that they are older than the Gleeson quartz monzonite in which they occur as inclusions, and definitely not as intrusive bodies. However, most of the rocks in question are so closely associated with the Pinal schist that it seems reasonable that they were originally injected into that formation. None have been found with younger stratigraphic units, and it seems likely, therefore, that the intrusions were emplaced in pre-Cambrian time.

SAUSSURITIC QUARTZ MONZONITE NEAR DRAGOON CAMP

Granitic rocks whose relations suggest that they may be pre-Cambrian are found both north and south of Dragoon Camp. For nearly 1½ miles southeast of the old Dragoon Camp (Black Diamond), a fault block that includes some Pinal schist at its northern end, and a discontinuous cover of Bolsa quartzite on its top, is largely made up of chloritic granitoid rock. The fault block rests on the Bisbee formation. The contact with the overlying Bolsa quartzite is apparently an unconformity, suggesting that the granitoid rock is pre-Cambrian, but the exposures do not suffice to prove it.

On the northern end of the peak north of Dragoon Camp very similar rock crops out. It invades the Pinal schist and at several localities is overlain with apparently depositional contact by the Bolsa quartzite. Normally, this evidence would suffice to prove the intrusion to be pre-Cambrian, but the base of the Bolsa is evidently a favorable horizon for intrusion at other places—notably east of Sandy Bob Ranch, where the Juniper Flat granite, definitely of post-Paleozoic age, has contacts with the Bolsa that appear conformable for many hundreds of feet and are only crosscutting in a few places. Hence, though a pre-Cambrian age still seems most reasonable, it is possible that the few contacts of the intrusion and Bolsa north of Dragoon Camp are only apparently depositional, and the intrusion is really post-Bisbee as it has been interpreted by Cederstrom (1946, p. 606, pl. 1) for the northerly areas, although he also assigned the southerly outcrops to the pre-Cambrian. This younger age assignment is supported by the fact that the Cochise quartz monzonite, to the north along the same thrust block, invades the Bisbee formation and petrographically resembles the quartz monzonite at Dragoon Camp very closely. Nevertheless, petrographic similarity constitutes a poor argument for correlation between such highly sheared and altered rocks as these, and it seems more reasonable to accept the local indications that the quartz monzonite is pre-Bolsa in age. The mass to the south of Dragoon Camp seems certainly to be correlated with that to the north, and hence it, too, is regarded as pre-Cambrian, as its poorly exposed contacts suggest.

Similar rocks are exposed on the western foot of the range about 1½ miles to the southwest. Here, again, the Bolsa quartzite appears to rest on the intrusion with profound nonconformity. Although exposures of the contact are poor and the intrusion closely resembles the Gleeson quartz monzonite of post-Paleozoic age a mile or two farther south, the fact that no dikes were seen and the Bolsa quartzite has essentially uniform thickness for more than a mile along the contact renders it all but certain that the contact is indeed a nonconformity and the intrusion is pre-Cambrian.

These rocks are all considerably brecciated, and it is apparent in hand specimens that they have all been crushed and chloritized. The color ranges from greenish gray to pinkish gray, depending on the amount of pink feldspar present. Quartz, plagioclase, microcline, muscovite, and chlorite are the megascopic minerals. In thin section the plagioclase is seen to be thoroughly saussuritic, packed with sericite plates and epidote grains, in an albitic base. Microcline-perthite, muscovite, and quartz are the other light minerals; and chlorite, much of it pseudomorphic after biotite along with the muscovite, is the only other essential constituent. Apatite, some of it in corroded grains, sphene, and magnetite are accessory. All the specimens examined show cataclastic textures, mortar structure, with a crystalloblastic intergrowth of the quartz and microcline, which hold the plagioclase breccia fragments poikilitically, though they are themselves commonly broken.

Petrographically these rocks resemble the altered facies of the Gleeson and Cochise Peak quartz monzonites and would be indistinguishable from them except on the basis of their geological relations.

PRE-MIDDLE CAMBRIAN UNCONFORMITY

The surface separating the Pinal schist and the rocks intruding it from the overlying Cambrian Bolsa quartzite is one of very low relief. Good exposures of the actual contact are very few, owing to the ready erosion of the Pinal with consequent masking of the contact by talus from the overlying quartzite. Nevertheless, it is clear from the mapping that local relief of the surface can hardly exceed a score of feet in several hundred feet of strike length.

The surface is thus either a peneplain or a plain of marine abrasion of remarkable smoothness. Its development must have occupied a very long period, for it is of comparable monotony wherever exposed in the Mule, Dragoon, Whetstone, and Swisshelm Mountains.

CAMBRIAN SYSTEM

MIDDLE CAMBRIAN SERIES

BOLSA QUARTZITE

NAME

The name Bolsa quartzite was proposed by Ransome for the basal quartzite of the Cambrian system at Bisbee (Ransome, 1904, p. 28) and was later applied by him to the undoubtedly correlative rocks of the Tombstone (Ransome, 1916, p. 148) and Turquoise (Ransome, 1913, p. 126) districts.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Bolsa quartzite crops out in two relatively extensive areas—south of Tombstone and along the western side of the Dragoon Mountains from South Pass to Gordon Camp—as well as in many smaller areas, chiefly individual fault blocks. Of these smaller masses, the more conspicuous are on Turquoise Ridge west of Courtland; on the east flank of Reservoir Hill and extending southeast to the Mary Mine in the Courtland district; on Black Diamond Peak, near Middlemarch Canyon; in the foothills south of the Fourr Ranch; on both sides of the mouth of Cochise Stronghold; and on the ridge extending north from the site of Harlan School (abandoned) and west of Sandy Bob Ranch in the foothills of the Mule Mountains. Scattered smaller fault blocks of Bolsa quartzite occur near Gleeson, near Barrett's Camp, and high on the Dragoon Mountains west of Walnut Springs.

The Bolsa quartzite is more resistant to erosion than any other formation in the area. It forms high ridges where it is present in full thickness—for example, at Brown's Peak, west of Courtland, and Ajax Hill, in the Tombstone Hills—and even small shattered blocks generally form hills or strong topographic benches.

STRATIGRAPHY

The Bolsa quartzite is rusty brown on weathered surfaces and is conspicuous by reason of its color as well as its resistance to erosion. On fresh fracture the rocks composing it are largely white or light pinkish gray.

The base on which the Bolsa quartzite rests is a smooth surface carved across pre-Cambrian rocks, largely the Pinal schist.

The lower part of the Bolsa is quartzite conglomerate, which grades upward without sharp discontinuity into gritty quartzite. The pebbles of the conglomerate are chiefly milky white quartz in the Mule Mountains, Tombstone Hills, and Dragoon Mountains, but in the Whetstone Mountains to the west rose quartz is also conspicuous. The pebbles are mostly very well rounded, but some are subangular. In all localities seen the pebbles are mostly less than 10 centimeters in diameter; in the Dragoon Mountains few exceed 3 centimeters. The matrix is generally pebbly grit, and passage to the overlying beds takes place by the gradual diminution of the number of pebbles.

The principal part of the Bolsa is composed of pebbly grit, of an average grain size of perhaps 1 millimeter but containing practically throughout sporadic quartz pebbles up to about 1 centimeter across. The rocks are commonly crossbedded. The beds range from a few inches to as much as 10 feet in thickness, the average being perhaps 2 to 4 feet.

The transition to the overlying Abrigo limestone is apparently gradational and occurs by an increase in finer shaly material and thin platy micaceous sandstones (and quartzite) with eventually thin limestone beds. The locally shaly zone of thin-bedded rocks intervening between the massive quartzite and the lowest limestone is arbitrarily classified in the Abrigo. It is commonly about 50 feet thick, but in the Middle Canyon section of the Whetstone Mountains there are nearly 100 feet of thin quartzite and shale layers between the massive quartzite and the limestone phase of the Abrigo. This is doubtless the zone of the Pima sandstone and Cochise formation of Stoyanow (1936, p. 466–467), who reports fragments of Bolsa quartzite in the 4-foot sandstone bed to which he applied the name Pima. The widespread occurrence of intraformational conglomerates in the Cambrian of this region leaves little ground for emphasizing the significance of this particular one as worthy of formational rank. It seems clear that there is as yet no stratigraphic evidence of any significant break at this horizon. The Bolsa and Abrigo are here regarded as transitional into each other.

THICKNESS

In the Tombstone Hills, Ransome measured the Bolsa quartzite as 440 feet thick (Ransome, 1916, pl. 25), practically the same (430 feet) as in the type locality in the Bisbee district (Ransome, 1904, p. 28). During this survey a section was measured on the west flank of the Dragoon Mountains, 4.3 miles northwest of South Pass, where the thickness was computed at 302 feet. Later mapping suggests the possibility that this section may be in error owing to faulting and hence that not much stress should be laid on the apparent northward thinning suggested by these figures. The matter is discussed in the section of this report dealing with the regional relations of the Cambrian. Though the structure of the area east of the mouth of Cochise Stronghold is complex and accurate measurement was not attempted, the thickness of the Bolsa as shown by the mapping must be essentially as great as it is to the south.

Although the Bolsa quartzite is lithologically distinctive among the formations of the area, it is not everywhere possible to distinguish small fault slices of this quartzite from similar slices of quartzite from the Bisbee formation. No quartzite beds in the Bisbee approach the Bolsa in thickness, though many are several scores of feet thick. Fault slices thinner than about 50 feet may be excluded from the Bolsa if they contain pebbles of limestone, which are unknown in this formation; but if they are wholly siliceous, the reference of the slice to Bolsa or Bisbee must be made on the basis of associated slices of Pinal, Abrigo, or both (suggesting Bolsa) or of highly carbonaceous shale or limestone conglomerate (suggesting Bisbee). The map is probably not seriously in error because of the possible confusion of the two formations, though this possibility should be recognized.

CONDITIONS OF DEPOSITION

The Bolsa quartzite represents the littoral deposits of a sea transgressing over a smoothly worn plain carved upon the pre-Cambrian rocks. Its generally coarse texture at the base shows that deposition was in shallow water, and the interlamination of finer shaly beds with quartzite at the top strongly suggests that the deposition of the Abrigo was a direct continuation of sedimentation as the depth of the sea increased and the waves were no longer able to transport coarse detritus. As Ransome pointed out (Ransome, 1904, p. 30) it is probable that the quartz represented in the conglomerate in the lower part of the Bolsa was derived from the veins of quartz in the Pinal schist.

AGE AND CORRELATION

The Bolsa quartzite at its type locality was assigned by Ransome (1904, p. 30) to the Middle Cambrian on account of its conformable relation to the overlying Abrigo, from which fossils assigned to the Middle Cambrian were collected. Ransome pointed out that it is doubtless the equivalent of the Dragoon quartzite as described by Dumble (1902, p. 713–714) from the Dragoon Mountains but gave a new name, owing to the unsatisfactory description of Dumble's type section. Ransome later extended the name Bolsa to the rocks of the Tombstone Hills and Dragoon Mountains to which it is here applied. Of the soundness of this correlation there can be little doubt. The lithology of the formation is essentially identical in all these areas, and in each the Pinal schist is overlain with marked uncomformity by a comparable thickness of quartzite. In each section, too, the overlying Abrigo limestone, of unique lithology, rests conformably upon it—indeed apparently grades into it.

MIDDLE AND UPPER CAMBRIAN SERIES

ABRIGO LIMESTONE

NAME

The name Abrigo limestone was first applied by Ransome to the limestone of Cambrian age overlying the Bolsa quartzite in the Bisbee district. (Ransome, 1904, p. 30). He later extended the name to the Tombstone Hills (Ransome, 1916, p. 148). In 1927 Wilson recognized the limestone of Cambrian age of the Courtland–Gleeson district as Abrigo (Wilson, 1927, p. 19).

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Abrigo limestone crops out in two principal and many smaller areas within the boundaries of plate 5. The longest belt is along the Dragoon Mountains, for about 4 miles northwest of South Pass. The second large area is in the Tombstone Hills where a continuous belt of Abrigo exposure extends for 2 miles. A small discontinuous mass crops out on the east side of the valley traversed by Highway 80 where it turns north from Tombstone Canyon (Mule Mountains). Other still smaller outcrops of Abrigo limestone are found along Tombstone Canyon; in the complex faulted area in sec. 19, T. 21 S., R. 24 E., south of the Prompter fault in the Tombstone Hills; in the thrust-faulted area near Gleeson; on the east slopes of Turquoise Ridge and near the Mary Mine in the Courtland district; in a broken band that extends south from China Peak; in the foothills south of the Fourr Ranch; and near the Cochise Stronghold Ranger Station at the east base of the Dragoon Mountains.

The Abrigo limestone generally forms a subdued topography. With the overlying Martin limestone it occupies the interval between two very resistant ledge-forming formations, the Bolsa quartzite below and the massive Escabrosa limestone above. Thus, even on the ridges, the Abrigo limestone forms saddles; where a strike ridge is formed by the Escabrosa, the Abrigo commonly forms a concave slope beneath it. Nevertheless, exposures of the Abrigo are commonly very good—its subdued topographic expression results less from its own weakness than from the marked resistance of the Escabrosa and Bolsa.

STRATIGRAPHY

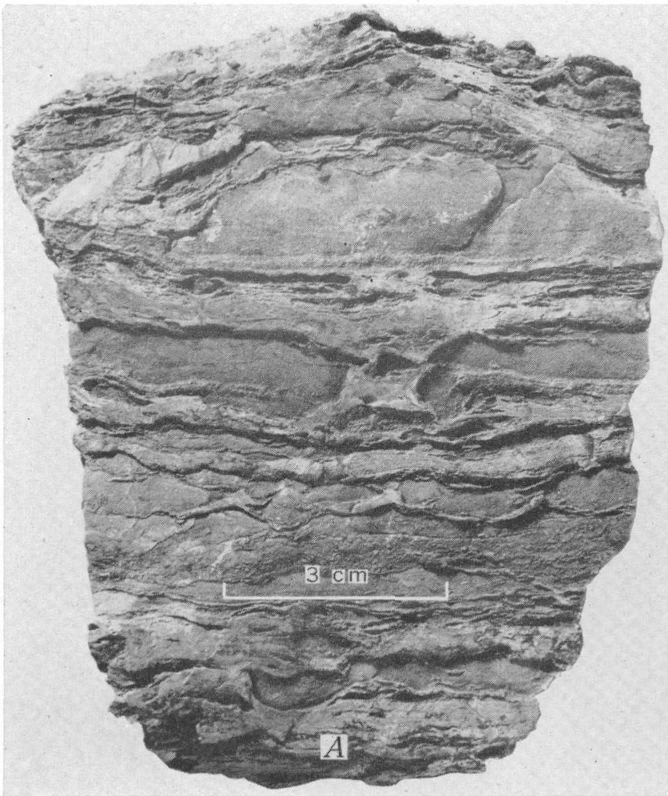
The contact of the Abrigo limestone with the underlying Bolsa quartzite is one of complete conformity and, indeed, in many localities is an entirely artificial division in a transitional series. The transition takes place through the interbedding of thin sandy micaceous shale layers in the quartzite, which likewise becomes thinner bedded upward. These shale layers become dominant over the quartzite within a few tens of feet—locally within a few feet—but commonly retain their sandy character through a thickness of several score feet. This part of the formation is usually greenish on fresh fracture but weathers to a dark brown.

Above this zone of dominant shale and sandstone, limestone, commonly with conspicuous edgewise conglomerates, appears and eventually dominates. The limestones are generally bluish gray, locally mottled with yellow, in beds mostly less than 4 inches thick. In places the mottling is apparently caused by carbonaceous or other inclusions in the limestone but generally by silty or micaceous material irregularly disposed in the limestone beds. (See pl. 1*A* and *B*.) The peculiar mottling of these limestones is locally suggestive of worm-burrowings, elsewhere of filled mud cracks and seaweed markings. None of these explanations of the features seems adequate to account for all their peculiarities, but the character of the markings is diagnostic of the formation in this area.

These silty parts of the Abrigo limestone are commonly silicified on weathered surfaces and many outcrops etch into patterns of relief. In some places cherty patches extend into the body of the rock for a considerable distance and may represent "stratigraphic chert," but in most exposures a fresh fracture shows only small areas or none that cannot be scratched with the pick. Most of the chert of the Abrigo appears to be superficial, in contrast with the persistent cherts of the limestones of Carboniferous age. A few thicker ledges of rather massive limestone interrupt the chiefly thin-bedded sequence. Toward the top of the formation, the beds become more dolomitic, and in the Dragoon and Swisshelm Mountains, there are a few ledges up to 12 feet thick of dolomite carrying enough well-rounded quartz grains to show marked crossbedding. Similar rocks have been described from the upper part of the Abrigo in the Bisbee district (Ransome, 1904, p. 32) and occur in the Middle Canyon area of the Whetstone Mountains, but they were not seen in the Tombstone Hills.

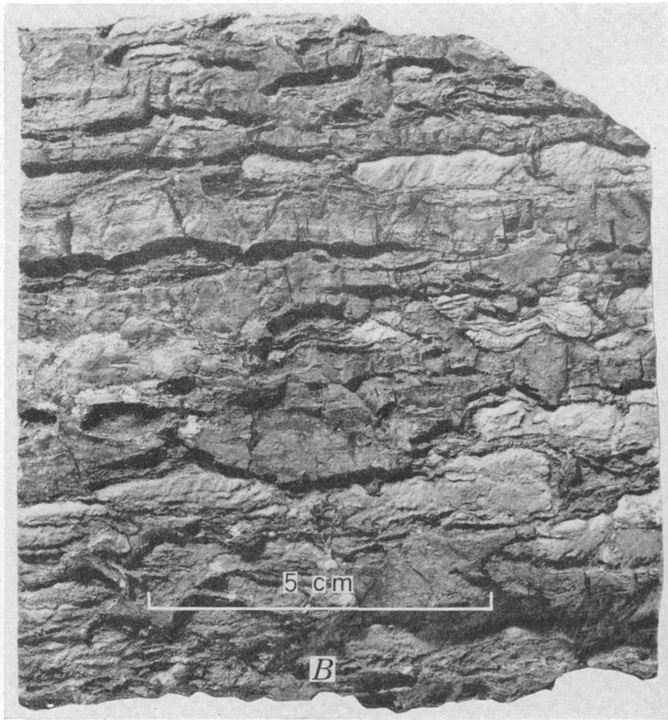
The Abrigo limestone becomes increasingly sandy in the upper part and is generally terminated upward by a ledge of sandstone or quartzite. It is clear from the gradual transition that this sandstone is part of the Cambrian sequence—even though no fossils have been found in it—and is not a basal bed of the overlying Martin limestone. This conclusion was long ago reached by Ransome (1904, p. 32) at Bisbee and has been accepted also by Stoyanow (1936, p. 470) and Bridge (personal communication, 1938).

The Abrigo limestone is the most distinctive formation in the area lithologically. The thin bedding, edgewise conglomerates, irregular interpenetrations of the argillaceous and carbonate layers, and the innumer-



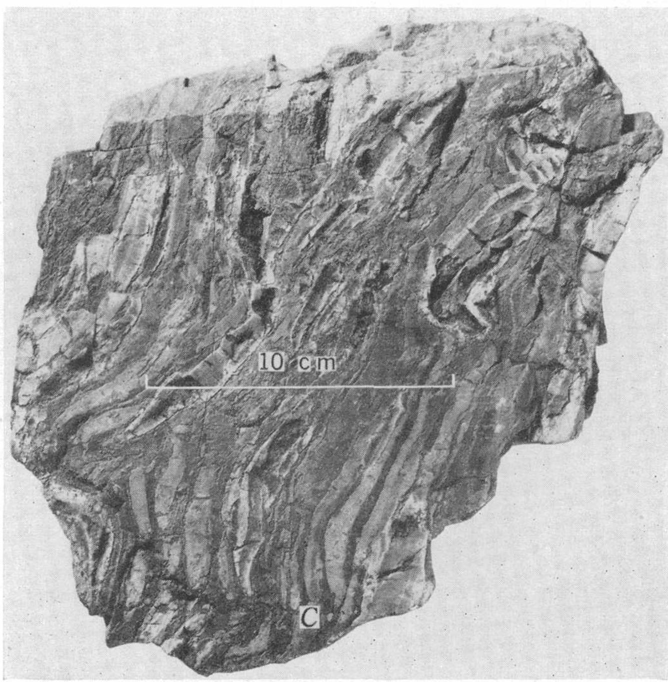
A. LIMESTONE SLIGHTLY ALTERED TO HORNFELS

Shows representative features of bedding. Irregular laminae of shaly and sandy material separate somewhat bulbous masses of sandy limestone.



B. HORNFELS

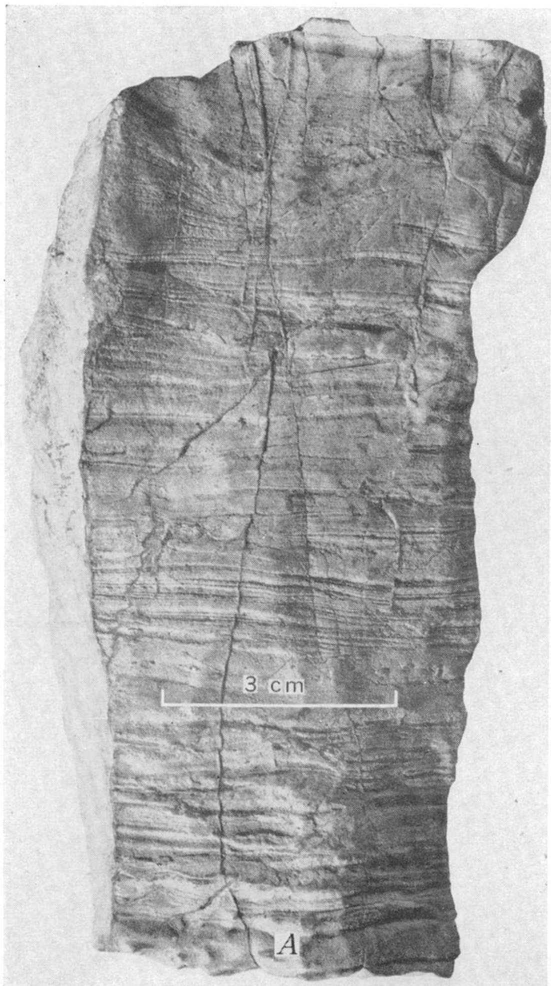
Epidote and garnet replace the former shaly partings between discontinuous layers of limestone.



C. SHEARED LIMESTONE, LATER ALTERED TO HORNFELS

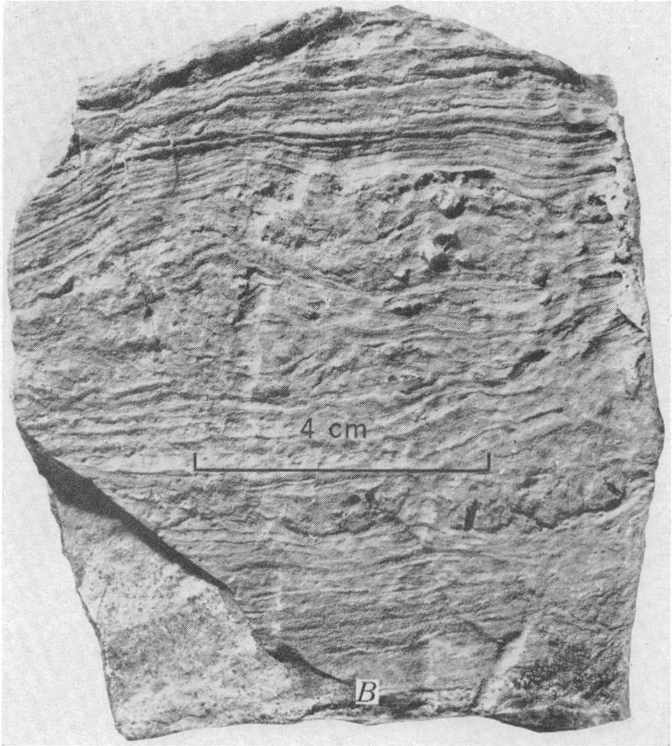
Shows persistence of the characteristic features of the limestone after severe metamorphism.

REPRESENTATIVE HAND SPECIMENS FROM THE ABRIGO LIMESTONE



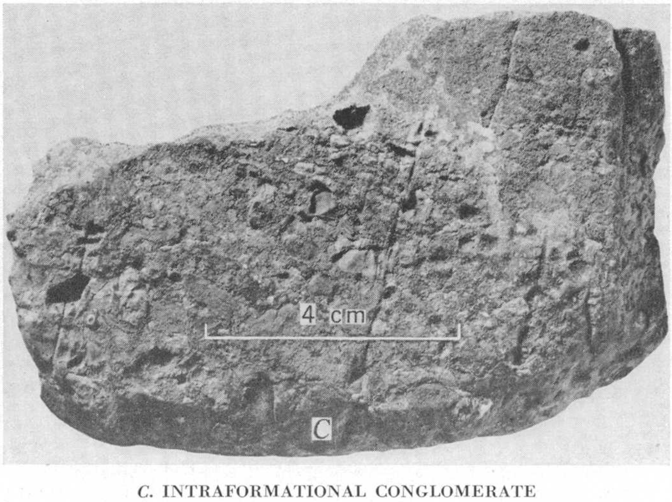
A. LAMINATED LIMESTONE

Pinkish tan, very fine grained, with well-marked crossbedding and a few minute nodules and thin irregular veinlets of silica.



B. IRREGULARLY BEDDED "ORANGE DOLOMITE"

Extremely fine-grained slightly sandy dolomite, dark purplish gray on fresh fracture, weathering here to a conspicuous tan that is splotched with brownish orange.



C. INTRAFORMATIONAL CONGLOMERATE

Pellets of red limestone, red shaly limestone, and gray limestone in a matrix of gray sandy limestone.

REPRESENTATIVE HAND SPECIMENS FROM THE EARP FORMATION able fucoidal and mud-crack markings are recognizable in even small outcrops and are, if anything, even more striking in areas of contact metamorphism than elsewhere. (See pl. 1*C*.) For this reason, the formation can be readily mapped wherever it occurs, even in the northern part of the Dragoon Mountains where metamorphism has destroyed the possibility of paleontological identification of the rocks. It constitutes the best marker unit of the area.

The following stratigraphic sections are representative of the Abrigo limestone in and near this area.

Section of Abrigo limestone east of Ajax Hill, Tombstone Hills (pl. 3, sec. 4)

[Numbers in brackets refer to fossil lots in the U. S. Geological Survey's catalog of collections of Cambrian fossils]

	Feet
Martin limestone:	
Limestone, dolomite, blue, massive beds	20
Abrigo limestone:	
1. Quartzite	2
2. Limestone, sandy, chiefly in beds a few inches thick, weather dark brown, some crossbedded, some sedimentary breccia layers; becomes increasingly sandy upward; [625] 4 feet below top, [626] 164 feet below top, [624] from 159 feet below top, [150] 204 feet below top, [623] 234 feet below top, [622] 254 feet below top, [149] 279 feet below top	296
3. Limestone, blue-gray, with a little oolite, mottled by shaly material; beds 2 inches to 2 feet thick, mostly about 3–4 inches; [621] 24 feet below top, [620] from 39 feet below top, [619] and [148] from 48 feet below top, [618] from 107 feet, and [617] from 123 feet below top	148
4. Edgewise conglomerate, limestone matrix with angular fragments of limy and sandy shale; [616] from middle of member	30
5. Limestone, blue-gray, thin-bedded, much mottled by shaly material	85
6. Sill, quartz porphyry	28
7. Limestone, very irregularly mottled by shaly material, "worm trails"; rill marks common; beds 2 inches to 2 feet thick, average 1 foot; [614] from 151 feet below top, [613] from 158 feet below top, [612] from 173 feet below top	208
8. Hornfels of green (epidotic) silicated limestone, much mottled, like member 7, with "worm trails"	15
9. Limestone and shale, interbedded; shale sandy and micaceous; limestone mottled and largely altered to hornfels; [610] from 37 feet, [609] from 10 feet above base of member	60
Total thickness Abrigo limestone	844
Bolsa quartzite:	
Quartzite, some very evenly bedded, some notably crossbedded, gritty, in beds 1–5 feet thick.	

Section of Abrigo limestone 1 mile due north of NW. corner of T. 19 S., R. 24 E.; on spur SW of 7150 B. M. about 2¼ miles south of Black Diamond Peak (pl. 8, sec. 5)

[Numbers in brackets refer to lots in the U. S. Geological Survey's catalog of collections of Cambrian fossils]

	Feet
Martin limestone:	
Sandstone at base, gray, weathers brown, a little sandy dolomite at top	50
Abrigo limestone:	
1. Dolomite, sandy, massive, pink, gray on weathered surface, becomes sandier upward, with much crossbedding, terminated upward by a conglomerate carrying rounded fragments of dolomite up to 6 inches in diameter and rounded quartz granules up to ⅛ inch in diameter	26
2. Sandstone, brown, to sandy limestone, in beds 4 inches to 2 feet thick, average about 8 inches	32
3. Dolomite, gray, coarsely crystalline, in beds 4 feet or more thick	46
4. Dolomite, pink, weathers brownish gray; considerable sandstone in beds averaging 1½ feet thick	95
5. Limestone, brown, mottled with reds and gray; some edgewise conglomerate and many thin sandy partings mostly about ¹⁄₁₆ inch thick but up to ½ inch thick, spaced every 2 or 3 inches; becomes more sandy upward, where it contains 2-foot beds of interbedded sandstone; [658] from 12 feet below top, [657] from 40 feet below top	89
6. Sandstone, brown, crossbedded, lime-cemented, with a few gray crystalline limestone beds up to about 4 inches in thickness; very fossiliferous; [656] from 4 feet below top	44
7. Limestone, gray, in layers 1–2 inches thick, separated by partings of shaly sandstone ⅛–½ inch thick, somewhat contorted by sedimentary processes; [655] from middle of member	80
8. Edgewise conglomerate	1
9. Limestone, mottled, in beds 2–4 feet thick that contain sandy streaks ½–2 inches apart; sandy streaks weather dark brown; member becomes slightly shaly upward; [654] from top, [653] from 15 feet below top; possibly faulted	200
10. Shale	4
11. Hornfels, dark-gray limy shale with some 2- to 6-inch partings of sandstone	5
12. Shale, green, weathers brown, micaceous, some brown weathering sandstone layers up to 6 inches thick in upper part	78
13. Sandstone to sandy limestone, weathers light brown; forms ledge	1½
14. Limestone, sandy, mottled, and contorted by sedimentary processes; contains some edgewise conglomerate and thin shale partings	26
15. Limestone, dolomitic, dark-gray spheroids, algal?, about 1 cm long, in a lighter gray matrix	1

Abrigo limestone—Continued	Feet
16. Edgewise conglomerate, sandy, blue-limestone matrix	2
17. Shale and limestone, micaceous, platy, thin alternations (3 inches), mottled with blue and yellow; and some edgewise conglomerate; very poorly exposed; forms a saddle in the ridge	105
Total Abrigo limestone	835½

Bolsa quartzite, poorly exposed.

Section of Abrigo limestone, Middle Canyon, Whetstone Mountains (pl. 8, sec. 2.)

[Numbers in brackets refer to lot numbers in the U. S. Geological Survey's catalog of collections of Cambrian fossils]

Martin limestone:	Feet
Dolomite, massive ledge, dove-colored, with quartz-lined geodes; carries *Atrypa* in upper part, base of Martin limestone.	
Abrigo limestone:	
1. Sandstone, gray, crossbedded, in beds a few inches thick; some 2-foot quartzite beds near top	27
2. Dolomite, pinkish-gray, massive, passes upward into conglomerate like that of member 3 which forms upper part of member	20
3. Conglomerate, limestone pebbles, largely subrounded, in sandstone matrix that weathers very dark brown at top; grades down into sandy dolomite, pinkish-gray, in beds averaging about 2 feet thick, unidentifiable fossils	27
4. Edgewise conglomerate, contains angular and roundish fragments of chert and shaly lenses in dolomitic matrix	8
5. Sandstone, limy; alternates in beds 2–4 feet thick, with sandy limestone	75
6. Limestone, bluish-gray, with considerable edgewise conglomerate, interbedded with considerable thin greenish shale that weathers olive drab, [634] from 7 feet above base of member	32
7. Limestone, similar to member 6, but fewer shale partings, hence thicker bedded but showing thin lamination on weathered surfaces; [633] from 37 feet above base	52
8. Limestone, in beds 1–2 inches thick, separated by thin reddish shale partings; forms steeper slope than underlying member but no sharp contrast; [630] from 17 feet above base, [631] from 24 feet above base, [632] from top	32
9. Limestone, like member 8 but more pinkish shale partings; [629] from top, [628] from 15 feet above base	25
10. Limestone, in beds 2–4 inches thick, separated by thin partings of pinkish sandy shale that weather dark brown	42½
11. Limestone, massive ledge, some thin shale partings not expressed in weathering	7
12. Shale, micaceous and sandy, green, a few limestone beds about 3 inches thick scattered through it	101
13. Limestone, blue-gray, forms prominent ledge	4
14. Hornfels, originally limestone and shale; that originally limestone in beds a few inches to 6 feet in thickness, averages about 2 feet; that originally shale is brown, in the irregular bedding characteristic of Abrigo elsewhere; limestone increases upward	27
15. Hornfels, originally limestone and shale, chiefly limestone above, prominent ledge at top; originally shaly partings, though hornfels, preserve irregular "worm tracks" and rill marks of original rock	78½
16. Hornfels, originally limestone and shale, increasingly limy toward top, shaly toward bottom; "worm tracks" and rill marks plentiful; ledge at the top with smooth slope below; [627] found in float here undoubtedly from this member	86
17. Shale, irregular "worm tracks," rill marks and ripple marks; increasingly limy upward; considerably metamorphosed to hornfels	51
18. Quartzite, crossbedded, gritty, forms prominent ledge	2
19. Shale, sandy, micaceous, with 2-foot quartzite ledge near middle of member	52
Total Abrigo limestone	749

Bolsa quartzite:
Quartzite, flaggy, in beds a few inches to 2 feet thick.

Section of Abrigo limestone, Little Dragoon Mountains, about 1½ miles northeast of Seven Dash Ranch House (pl. 8, sec. 6)

[Numbers in brackets refer to lot numbers in the U. S. Geological Survey's catalog of collections of Cambrian fossils]

Martin limestone:	Feet
Dolomite, dove-colored, not sandy, weathers with elephant-hide surface, yellow gray, forms ledge	7
Abrigo limestone:	
1. Quartzite composed of well-rounded grains of quartz, jasper, and black chalcedony about 1 millimeter in diameter; massive at base (5 feet) but thinner bedded and less well cemented toward top	12
2. Sandstone, dolomitic, alternates with sandy dolomite, dominantly sandstone, in beds up to 4 inches thick; hard at base but less well cemented toward top	42
3. Dolomite, pinkish-gray, weathers buff and brown, coarsely crystalline, mottled by irregular stringers of sand; beds 2–8 inches thick	46
4. Quartzite, crossbedded, in layers 4–18 inches thick	4
5. Dolomite, sandy, alternates with sandstone; 3-inch sandstone bed at base, then 9 inches of coarsely crystalline gray dolomite that weathers dark brown, followed by alternating thin beds of sandstone and dolomite	24
6. Limestone, coarsely crystalline, mottled by irregular sand stringers every inch or so, with some edgewise conglomerate and several 2- to 6-inch beds of trilobite coquina; [738] at 23 feet above base, [739] at 42 feet above base	48

Abrigo limestone—Continued	*Feet*
7. Hornfels, originally limy shale and sandstone, crossbedded, weathers greenish brown, with deeply etched surface; forms prominent ledge	4
8. Sandstones, interbedded in 6-inch beds; edgewise conglomerate with limestone matrix in ½- to 2-inch beds; a little thin-bedded limestone and one brown dolomite bed	25
9. Sandstone, green-gray, weathers dark brown, crossbedded, in layers 1–4 inches thick, with a few limestone interbeds	33
10. Limestone conglomerate; forms ledge	1
11. Limestone, gray, mottled brown owing to shaly material spaced at ½- to 1-inch intervals, becomes slightly sandy in top 20 feet; [737] at 62 feet above base	174
12. Limestone and sandstone, interbedded in thin beds	12½
13. Shale, brown	6
14. Edgewise conglomerate, consists of sandstone fragments in limy matrix	3
15. Quartzite	½
16. Sandstone, brown, interbedded with subordinate amounts of limestone and mottled shaly limestone and limestone conglomerate	34
17. Shale, greenish-brown, micaceous, sandy and limy, with ripple and rill marks and fucoids; a few thin, 2- to 4-inch crossbedded sandstones and some blue limestone, mottled yellowish by shaly material	34
18. Limestone, dark-blue-gray, mottled with yellow-weathering silt and brown-weathering sandstone in very irregular layers; several 2- to 3-inch sandstone layers; some micaceous shale; several 3- to 4-inch layers of limestone carry round black "algal" colonies; forms gentle slope; [734] at base, [735] about 12 feet above base	48
19. Limestone, dark-blue-gray, mottled with yellow-weathering silt and brown-weathering sandstone spaced ½–2 inches apart and ⅛–½ inch thick; weathering brings out bedding of limestone as a whole as 4 inches to 2 feet thick; much less sandy than member 24; forms subdued ledge	29
20. Shale, green-brown, weathers yellow-brown, micaceous, sandy; increasingly limy upward; contains a few 3-inch layers of blue-gray-mottled limestone toward the top	52½
21. Limestone, blue-gray, mottled with irregularly arranged siltstone that weathers yellow brown; beds 8–12 inches thick; forms a strong ledge	4½
22. Limestone, blue-gray, like member 27 but in beds chiefly only 1–2 inches thick	44½
23. Limestone, dark-gray, weathers strong yellow brown; has partings of sandy stringers that weather out on surface; many stringers irregular, joining and parting along the strike; stringers 1/16–½ inch thick and average about ¼–4 inches apart; forms prominent ledge of beds about 1 foot thick	8½
24. Limestone, sandy, with limy sandstone at base in beds 4–8 inches thick; passes upward through mottled 4-inch limestone beds with ½-inch sandstone partings and becomes more limy; poorly exposed	64
25. Quartzite, massive	3
26. Shale, sandy, interbedded in layers ½-inch or so thick; quartzite in beds 6–12 inches thick; about 3 times as much shale as quartzite	46
Total Abrigo limestone	803

Bolsa quartzite:

Quartzite, crossbedded, with *Scolithus* tubes and worm trails, beds about 1–3 feet thick.

Partial section of Abrigo limestone, northwestern spur, Swisshelm Mountains, sec. 15 (unsurveyed) T. 20 S., R. 27 E. (pl. 8, sec. 7)

[Numbers in brackets refer to lots in the U. S. Geological Survey's catalog of collections of Cambrian fossils]

Top eroded, section begins on hilltop.	*Feet*
1. Dolomite, dark-gray, very little sand; a 4-foot sandy limestone at base and a 3-foot crossbedded partly sandy quartzite at the top; unidentifiable fossils from about 20 feet below top	30
2. Dolomite, gray, crystalline, in 2-foot beds, a little sandstone	34
3. Limestone, sandy, mottled with "worm trails"	2
4. Dolomite, dark-gray, crystalline, a very little sand; bedding averages 6–8 inches; [749] from base	51
5. Sandstone, dolomitic, interbedded sandy dolomite; forms low slope, capped by 2-foot ledge of sandy quartzite, [748] from 40 feet below top	59
6. Quartzite, forms ledge	3
7. Sandstone, in crossbedded layers averaging 2 feet thick, grades in lower 15 feet into very sandy yellow dolomite, contains much edgewise conglomerate; sandstone cemented by dolomite; bedding extremely irregular and lenticular	142
8. Limestone, thin-bedded, sandy, interbedded with limy sandstone, much ripple marked and crossbedded and grading into member 7; many layers of edgewise conglomerate throughout; [747] from 2 feet below top	34
9. Limestone, mottled in grays, some sandy but mostly shaly, with streaks and small rounded masses of clay that weather yellow; beds 4 inches to 4 feet thick, average about 8 inches in lower part but only about 2 inches toward top. [746] about 55 feet below top; [745] about 4 feet above base	114
10. Sandstone, limy toward top, massive, crossbedded and ripple-marked; forms ledge	4
11. Sandstone, limy weathers dark brown, some thinner shale interbeds; poorly exposed; forms smooth slope	34
12. Limestone, in 3-foot ledges, many mottled with black algal(?) concretions, alternating with thin-bedded sandy micaceous shale, 2-inch ripple-marked sandstone at top	33

	Feet
13. Sandstone and sandy shale, a few 2-inch interbeds of limestone conglomerate and one conglomerate layer 3 feet thick at top	17
14. Sandstone, limy, mottled with limestone; forms ledge	2
15. Shale, sandy micaceous; weathers greenish yellow; a little interbedded limestone	55
16. Limestone, blue-gray, mottled with yellowish-weathering streaks of shaly material; beds 6 inches to 1 foot thick; some intraformational conglomerate near base; [744] from near base	27
17. Dolomite, gray, crystalline; weathers dark brown, in 2- to 4-foot ledges; mottled with a little sand	19
18. Shale, micaceous and sandy, a few 1-inch sandstone layers; [743] at base	31
19. Sandstone, limy, a little shale; beds 1 foot or less thick	14
20. Shale, sandy, thin layers of limestone and of micaceous sandstone; [741] from base	23
21. Quartzite and shale, interbedded in layers 8 inches to 1 foot thick; forms a saddle	50
Partial section, Abribo limestone	778

Bolsa quartzite:

Quartzite, light-gray to almost white, in beds 2–4 feet thick; crossbedded, with many *Scolithus* tubes and fucoid markings.

THICKNESS

At the type locality of the Abrigo limestone, in the Bisbee district, its thickness was measured by Ransome (1904, p. 31) as 770 feet. Measurements made during this survey, as given in the detailed sections, indicated thicknesses of 844 feet in the Tombstone Hills (probably thickened by a small fault), 835 feet in the southern Dragoon Mountains, 749 feet in the Whettonse Mountains to the west, 778 feet (partial section) in the Swisshelm Mountains to the east, and 803 feet in the Little Dragoon Mountains to the northwest. (See pl. 8.) All these sections were studied in company with Dr. Josiah Bridge. In three sections no fossils were found near the top, so that members 1 and 2 (47 feet) in the Whetstone section, members 1 to 4 inclusive (104 feet) in the Little Dragoon Mountains section, and members 1 to 4, inclusive (199 feet) in the Dragoon Mountains section may not be properly referable to the Abrigo.

AGE AND CORRELATION OF THE ABRIGO LIMESTONE

By A. R. Palmer

Four collections made by Gilluly and Bowles in 1937 and 66 collections made by Bridge, Gilluly, Cannon, and Hass in 1938 have been used to prepare a preliminary report on the faunal content of the Abrigo limestone in central Cochise County. The collections were made from the following six measured sections (fig. 2; pl. 8):

1. Ajax Hill, 4 miles south of Tombstone, Ariz. (Benson quadrangle).
2. Mount Martin, 1½ miles west-northwest of Bisbee, Ariz. (Bisbee quadrangle).
3. Whetstone Mountains, in Middle Canyon, 11 miles southwest of Benson, Ariz. (Benson quadrangle).
4. Swisshelm Mountains, 3½ miles south-southeast of the Whitehead Ranch (Pearce quadrangle).
5. Dragoon Mountains, 1½ miles south of Dragoon Camp (Pearce quadrangle).
6. Little Dragoon Mountains, ½ mile southeast of Seven Dash Ranch (Dragoon quadrangle).

The faunas of the Abrigo limestone range in age from late Middle Cambrian through at least two-thirds of the Late Cambrian. Representatives of possibly several late Middle Cambrian zones; the *Cedaria*, *Crepicephalus*, and *Aphelaspis* zones of Dresbach age (early Late Cambrian); and the *Elvinia*, *Conaspis*, and *Ptychaspis* zones of Franconia age (middle Late Cambrian) are present. An alphabetical list of all of the identified fossils and a faunal list by section and horizon are given on pages 21–22.

Acetic acid residues of all of the limestone collections and hydrochloric acid residues from a few collections containing silicified brachiopods have been prepared. All of the fossiliferous acetic acid residues are of Dresbach age and principally from the middle of the *Cedaria* zone. Here, rather abundant specimens of *Dicellomus* occur through about 50 feet of section, forming an excellent faunal marker horizon.

All of the Cambrian faunas recognized here are widespread in the Cordilleran region. Faunas of Dresbach age are particularly well represented in the collections. Many of the trilobite species of Dresbach age in the Abrigo limestone are nearly identical to forms in the Pilgrim limestone in central Montana and the Riley formation in central Texas. Faunas of Middle Cambrian and Franconia age tend to show similar relationships, but adequate comparisons are hindered by relatively poor and inadequate material from these parts of the section. More collecting in this region should fill in some of the gaps in the present faunal sequences and aid the development of a satisfactory zonation of the Cambrian rocks of the Cordilleran region.

In general, the information available in this study supports the paleogeographic conclusions of Stoyanow (1942, pl. 5, fig. d) and Lochman (1949, pl. 8, opposite p. 64) for the sediments of Dresbach age. There is a tendency toward thinning of the sections in the north and northeast (Little Dragoon and Swisshelm Mountains), together with an increase in the amount of sand in those directions which suggests approach to a source area.

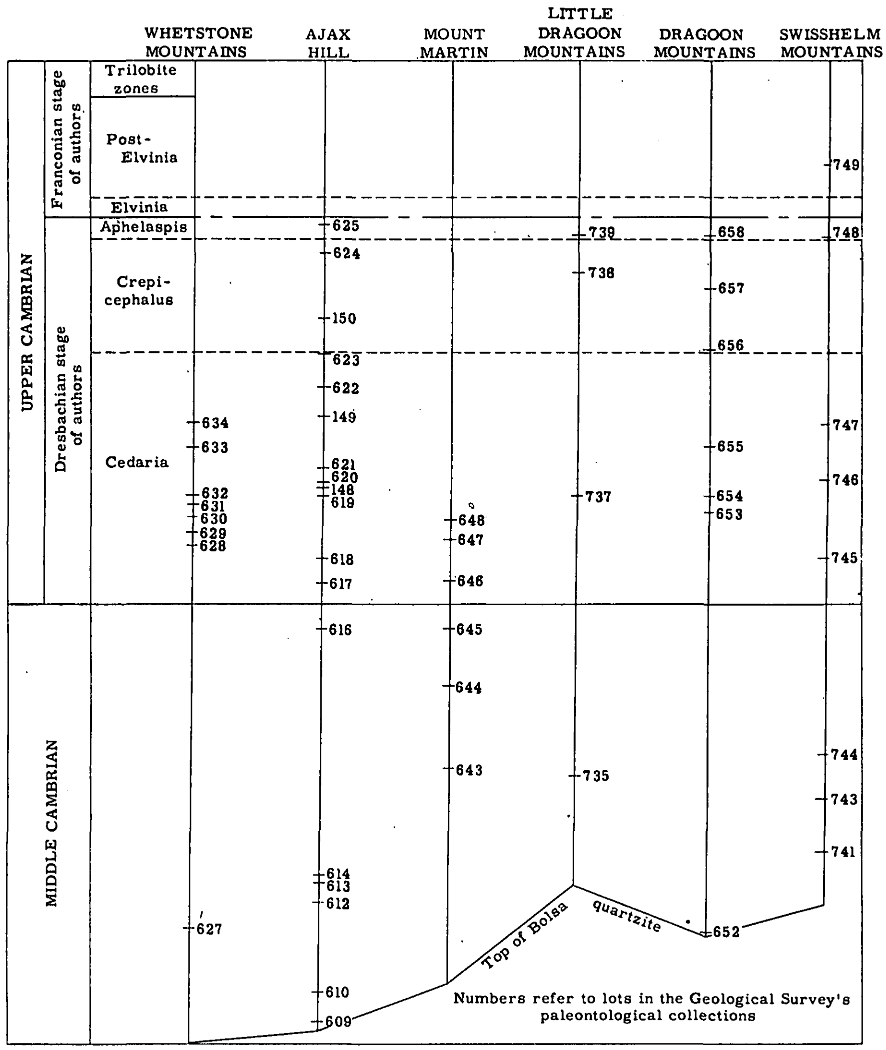


FIGURE 2.—Diagram showing faunal zones recognized in the Abrigo limestone, with locations of the several fossil collections, by A. R. Palmer.

Identified fossils of the Abrigo limestone

Trilobites

Albansia cf. *A. montanensis* (Howell and Duncan)
Ankoura? sp.
Aphelaspis walcotti Resser
Arapahoia ransomei (Stoyanow)
Armonia cf. *A. lata* (Howell and Duncan)
Aspidagnostus? sp.
Blountia sp.
Bolaspidella sp.
Brassicicephalus spp.
Bynumia? sp.
Cedarina cf. *C. cordillerae* (Howell and Duncan)
 cf. *C. nixonia* Lochman
Cheilocephalus sp.
Coosella cf. *C. connata* (Walcott)
 sp.
Coosia sp.
Drumaspis sp.
Ehmania sp.
Eldoradia sp.
Ellipsocephaloides sp.
Genevievella? sp.
Glyphaspis sp.
Holcacephalus appalachius Resser
 tenerus (Walcott)
Kingstonia spicata Lochman
 spp.
Kormagnostus cf. *K. simplex* Resser
 sp.
Llanoaspis undulata Lochman
Maladia? sp.
Maryvillia cf. *M. ariston* Walcott
Meteoraspis cf. *M. borealis* Lochman
Menomonia sp.
Nixonella sp.
Nixonella? cf. *N.? wolfensis* Lochman
Olenoides? sp.
Paracedaria montanensis (Duncan)
Prosaukia sp.
Pseudagnostus sp.
Pterocephalia? sp.
Raaschella ornata Lochman

Semnocephalus cf. *S. centralis* (Whitfield)
Syspacheilus cf. *S. dunoirensis* (Miller)
cf. *S. occidens* Lochman
Tricrepicephalus cf. *T. texanus* (Shumard)
cf. *T. coria* (Walcott)
sp.
Wilbernia sp.

Brachiopods

Billingsella perfecta Ulrich and Cooper
Dicellomus nanus Walcott
"*Dictyonina*" sp.
Eoorthis sp.

Problematica

Kinsabia sp.

Fauna by sections and zones

[Numbers refer to assigned numbers in the U. S. Geological Survey's collections. Brachiopods and problematica marked with an asterisk]

Ajax Hill section (pl. 3, sec. 4)

Upper Cambrian (Dresbach age):
Aphelaspis zone:
USGS 625:
Aphelaspis walcotti Resser
USGS 626:
Crepicephalus sp.
USGS 624:
Crepicephalus? sp.
USGS 150:
Brassicicephalus sp.
Holcacephalus appalachius Resser
Kormagnostus cf. *K. simplex* Resser
sp.
Tricrepicephalus cf. *T. coria* (Walcott)
Cedaria zone:
USGS 623:
Ankoura? sp.
Meteoraspis cf. *M. borealis* Lochman
Nixonella? cf. *N.? wolfensis* Lochman
Tricrepicephalus cf. *T. coria* (Walcott)
USGS 622:
Aspidagnostus? sp.
Coosella sp.
Genevievella? sp.
Meteoraspis cf. *M. borealis* Lochman
sp.
Nixonella sp.
Tricrepicephalus cf. *T. texanus* (Shumard)
**Dicellomus nanus* Walcott
USGS 149:
Brassicicephalus sp.
Cedaria cf. *C. nixonia* Lochman
Coosella sp.
Genevievella? sp.
Holcacephalus tenerus (Walcott)
Kormagnostus cf. *K. simplex* Resser
Kingstonia sp.
Menomonia sp.
Tricrepicephalus cf. *T. coria* (Walcott)
USGS 621:
Arapahoia ransomei (Stoyanow)
Cedarina cf. *C. cordillerae* (Howell and Duncan)
Kingstonia spicata Lochman
Meteoraspis cf. *M. borealis* Lochman
Tricrepicephalus sp.
**Dicellomus nanus* Walcott

Upper Cambrian (Dresbach age)—Continued
Cedaria zone—Continued
USGS 620:
Kormagnostus cf. *K. simplex* Resser
Meteoraspis cf. *M. borealis* Lochman
USGS 148:
Arapahoia ransomei (Stoyanow)
Cedaria cf. *C. nixonia* Lochman
Cedarina cf. *C. cordillerae* (Howell and Duncan)
Coosella sp.
Kingstonia sp.
spicata
Kormagnostus cf. *K. simplex* Resser
Meteoraspia cf. *M. borealis* Lochman
Tricrepicephalus? sp.
**Dicellomus nanus* Walcott
USGA 619:
Cedaria cf. *C. nixonia* Lochman
Cedarina cf. *C. cordillerae* (Howell and Duncan)
Coosella sp.
Kingstonia spicata Lochman
Kormagnostus cf. *K. simplex* Resser
Meteoraspis cf. *M. borealis* Lochman
Semnocephalus centralis (Whitfield)
**Dicellomus nanus* Walcott
USGS 618:
Cedarina cf. *C. cordillerae* (Howell and Duncan)
Coosella sp.
USGS 617:
Kingstonia sp.
Middle Cambrian:
USGS 616:
Eldoradia sp.
USGS 614:
Genus and species undetermined
USGS 613:
Genus and species undetermined
USGS 612:
Olenoides? sp.
USGS 610:
Genus and species undetermined
USGS 609:
Glyphaspis sp.

Whetstone Mountain section (pl. 8, sec. 2)

Upper Cambrian (Dresbach age):
Cedaria zone:
USGS 634:
Arapahoia ransomei (Stoyanow)
Semnocephalus centralis (Whifield)
USGS 633:
Arapahoia ransomei (Stoyanow)
Kingstonia sp.
Meteoraspis cf. *M. borealis* Lochman
Pseudagnostus? sp.
Semnocephalus centralis (Whitfield)
Syspacheilus cf. *S. occidens* Lochman
**Dicellomus nanus* Walcott
USGS 632:
Arapahoia ransomei (Stoyanow)
Aspidagnostus? sp.
Cedaria cf. *C. nixonia* Lochman
Cedarina cf. *C. cordillerae* (Howell and Duncan)
Coosia sp.
Kormagnostus cf. *K. simplex* Resser

Upper Cambrian (Dresbach age)—Continued
 Cedaria zone—Continued
  USGS 632—Continued
   Meteoraspis cf. *M. borealis* Lochman
   Semnocephalus centralis (Whitfield)
   **Dicellomus nanus* Walcott
  USGS 631:
   Meteoraspis cf. *M. borealis* Lochman
  USGS 630:
   Arapahoia ransomei (Stoyanow)
   Cedaria cf. *C. nixonia* Lochman
   Kingstonia spicata Lochman
   Kormagnostus cf. *K. simplex* Resser
   Menomonia? sp.
   Meteoraspis cf. *M. borealis* Lochman
  USGS 629:
   Meteoraspis cf. *M. borealis* Lochman
  USGS 628:
   Kormagnostus cf. *K. simplex* Resser
   Meteoraspis cf. *M. borealis* Lochman
   Semnocephalus centralis (Whitfield)
Middle Cambrian:
  USGS 627:
   Genus and species undetermined

Mount Martin section (pl. 8, sec. 3)

Upper Cambrian (Franconia age):
 Ptychaspis zone:
  USGS 651:
   "*Agnostus*" *parilis*
   Drumaspis sp.
   Ellipsocephaloides? sp.
   Maladia sp.
   Pseudagnostus sp.
   Prosaukia? sp.
   Wilbernia sp.
   **Billingsella* sp.
Upper Cambrian (Dresbach age):
 Crepicephalus zone:
  USGS 650:
   Coosella sp.
   Coosia cf. *C. connata* (Walcott)
   Crepicephalus sp.
   Tricrepicephalus sp.
   **Kinsabia* sp.
  USGS 649:
   Coosella sp.
   Crepicephalus sp.
   Kormagnostus cf. *K. simplex* Resser
   Meteoraspis cf. *M. borealis* Lochman
   Tricrepicephalus cf. *T. coria* (Walcott)
   Tricrepicephalus cf. *T. texana*
 Cedaria zone:
  USGS 648:
   Cedarina cf. *C. cordillerae* (Howell and Duncan)
   Kormagnostus cf. *K. simplex* Resser
   Meteoraspis cf. *M. borealis* Lochman
   Semnocephalus centralis (Whitfield)
  USGS 647:
   Albansia? cf. *A.? montanensis* (Howell and Duncan)
   Cedarina cf. *C. cordillerae* (Howell and Duncan)
   Coosella sp.
   Meteoraspis cf. *M. borealis* Lochman
   **Kinsabia* sp.

Upper Cambrian (Dresbach age)—Continued
 Cedaria zone—Continued
  USGS 646:
   Ankoura? sp.
   Kingstonia sp.
Middle Cambrian:
  USGS 645:
   Eldoradia sp.
  USGS 644:
   Bolaspidella sp.
  USGS 643:
   Bolaspidella? sp.
   Ehmania sp.

Dragoon Mountains section (pl. 8, sec. 5)

Upper Cambrian (Dresbach age):
 Aphelaspis zone:
  USGS 658:
   Blountia sp.
   Cheilocephalus sp.
 Crepicephalus zone:
  USGS 657:
   Crepicephalus sp.
   Maryvillia cf. *M. ariston* Walcott
   Tricrepicephalus sp.
  USGS 656:
   Crepicephalus sp.
   Maryvillia cf. *M. ariston* Walcott
 Cedaria zone:
  USGS 655:
   Meteoraspis cf. *M. borealis* Lochman
   Tricrepicephalus cf. *T. texanus* (Shumard)
  USGS 654:
   Arapahoia ransomei (Stoyanow)
   Kingstonia sp.
   Meteoraspis cf. *M. borealis* Lochman
  USGS 653:
   Arapahoia ransomei (Stoyanow)
   Kingstonia spicata Lochman
   **Dicellomus nanus* Walcott

Little Dragoon Mountains section (pl. 8, sec. 6)

Upper Cambrian (Dresbach age):
 Aphelaspis zone:
  USGS 739:
   Aphelaspis walcotti Resser
   Raaschella ornata Lochman
   *"*Dictyonina*" sp.
 Crepicephalus zone:
  USGS 738:
   Crepicephalus sp.
   Llanoaspis undulata Lochman
   Maryvillia cf. *M. ariston* Walcott
   Tricrepicephalus cf. *T. coria* (Walcott)
 Cedaria zone:
  USGS 737:
   Arapahoia ransomei (Stoyanow)
   Cedaria cf. *C. nixonia* Lochman
   Cedarina cf. *C. cordillerae* (Howell and Duncan)
   Kormagnostus cf. *K. simplex* Resser
   Meteoraspis cf. *M. borealis* Lochman
   Paracedaria montanensis (Duncan)
   Semnocephalus centralis (Whitfield)
   Syspacheilus cf. *S. dunoirensis* (Miller)

Middle Cambrian:
USGS 735:
Ehmania sp.

Swisshelm Mountains section (pl. 8, sec. 7)

Upper Cambrian (Franconia age):
Conaspis zone:
USGS 749:
**Billingsella perfecta* Ulrich and Cooper
**Eoorthis* sp.
Elvinia zone:
USGS 748:
Pterocephalia? sp.
Upper Cambrian (Dresbach age):
Cedaria zone:
USGS 747:
Meteoraspis sp.
Tricrepicephalus sp.
USGS 746:
Cedarina cf. *C. cordillerae* (Howell and Duncan)
Kormagnostus cf. *K. simplex* Resser
Paracedaria montanensis (Duncan)
Syspacheilus cf. *S. dunoirensis* (Miller)
USGS 745:
Armonia cf. *A. lata* (Howell and Duncan)
Brassicicephalus sp.
Bynumia? sp.
Cedarina cf. *C. cordillerae* (Howell and Duncan)
Nixonella sp.
Middle Cambrian:
USGS 744:
Ehmania sp.
USGS 743:
Genus and species undetermined
USGS 741:
Genus and species undetermined

The Abrigo limestone of Ransome apparently contains beds of both Middle and Late Cambrian age. Because of the several faunal zones represented, Stoyanow (1936) proposed that Ransome's classification should be modified: that the name Abrigo be restricted to the middle part of the Abrigo as originally defined and that the lower 290 feet of strata in the type locality on Mount Martin, Bisbee quadrangle, be recognized as a new formation, the Cochise. Stoyanow also referred the top 81 feet, overlying his restricted Abrigo formation, to a second new formation, the Copper Queen limestone.

These proposals have not been adopted in the present report. Even if the subdivisions proposed by Stoyanow were lithologically separable over the entire area, which is considered unlikely, they constitute rather arbitrary segments of an apparently unbroken sedimentary series, too small to be shown on a map of the scale of plate 5. Their distinction in mapping would thus have been impractical as it would require exaggeration of at least some of the units, not believed to be warranted by their significance in geologic history. Further, like most of the subdivisions of transitional lithologic units that have been proposed on a purely faunal basis, the position of the map contacts would have depended unduly on subjective factors and accidents of fossil preservation. The widespread contact metamorphism that the Cambrian rocks have undergone has in many places destroyed all fossils, still further handicapping—if not, indeed, altogether preventing any consistent separation of the faunal zones. It seems that we have, in Ransome's Abrigo limestone, a formation closely analogous to such other Cordilleran formations as the Ophir shale and Manning Canyon shale (Gilluly, 1932, 9–12, 32–34; Nolan, 1935, 31–33; Calkins and Butler, 1943, p. 14), among others. These each contain distinctly different faunas in their upper and lower parts. But the faunal breaks occur within lithologically transitional strata, and the fossils are not abundant enough to be characteristic lithologic features useful in distinguishing beds. There is thus no objective way of distinguishing smaller map units within these formations over wide areas away from the fortuitously well-exposed places where the faunal zones have been recognized. Because a formation is the fundamental map unit (Ashley and and others, 1933, p. 429), these considerations have led to the retention of Ransome's original usage. All the Cambrian rocks above the Bolsa quartzite have been included in the Abrigo limestone.

REGIONAL RELATIONS OF THE CAMBRIAN ROCKS

The general distribution of the Cambrian in Arizona has been admirably summarized by Darton (1925, p. 38–52) and Stoyanow (1936, p. 465–481). A few of the data obtained during this survey permit some supplementary comment. (See pl. 8.)

The Bolsa quartzite is clearly recognizable in the following localities: Bisbee (type section), 430 feet (Ransome, 1904, p. 29); Tombstone Hills (this report), 440 feet; Dragoon Mountains (this report), 302 feet; Whetstone Mountains, 400 feet (Stoyanow, 1936, p. 480); Little Dragoon and Swisshelm Mountains (this report), not measured but several hundred feet thick in each locality. Both Darton and Stoyanow correlated it with the Troy quartzite (350 feet) in the Santa Catalina Mountains, and, with more apparent doubt on the part of Stoyanow, with the Coronado quartzite (100 to 250 feet) in the Clifton–Morenci district. This correlation had long previously been suggested by Lindgren (1905, p. 62). Darton's reconnaissance suggested a thickness of 150 feet for quartzites that he correlated with the Bolsa in the Dos Cabezas Mountains about 25 miles northeast of the Dragoon Mountains (1925, p. 296). All these localities expose essentially identical quartzites resting in profound unconformity upon older rocks referred to the pre-Cambrian. In all localities these quartzites are overlain by conformable beds containing

Cambrian fossils. There can thus be little doubt of their stratigraphic equivalence, though the faunal zoning of the overlying rocks is not well enough known to make certain of their precise age equivalence in all the sections. The quartzite itself has yielded no fossils except perhaps on Chase Creek, Morenci district, where some brachiopods, referred with doubt to the Middle Cambrian by Walcott (1912, p. 516), were found by J. M. Boutwell. Walcott later referred to these collections as having come from siliceous limestone beds 15 feet above the quartzite (Lindgren, 1905, p. 61). Whether from within or above the quartzite, the significance would hardly be altered as the beds overlying the quartzite are also of Middle Cambrian age in the more southwesterly localities.

The Bolsa apparently thins to the northeast, being only 150 feet thick in the Dos Cabezas Mountains (Darton, 1925, p. 296); and its equivalent, the Coronado, being variable, reaches its maximum of 250 feet near Morenci (Lindgren, 1905, p. 59–60). The sporadic distribution of the basal conglomerate, the absence of granitic pebbles even where it rests widely upon pre-Cambrian granite, and the local variations in thickness suggested to Lindgren that at Morenci it overlies a deeply weathered surface of low relief and that at least its basal beds are fluviatile. These facts suggest that as the eastern limit of the depositional basin is approached, the base may be somewhat younger.

The Abrigo limestone in the sense defined by Ransome is represented in neighboring ranges by the following thicknesses:

	Feet
Santa Catalina Mountains (Stoyanow, 1936, p. 477, Santa Catalina, Southern Belle, Abrigo, and Peppersauce Canyon formations)	724
Whetstone Mountains	749
Tombstone Hills	844
Tombstone Hills (Ransome, 1916, p. 25)	700
Dragoon Mountains	835
Little Dragoon Mountains	803
Swisshelm Mountains	778
Mule Mountains (Ransome, 1904, p. 31)	770

It is a striking fact that despite the disconformity represented at the top of each of these sections—for the next succeeding rocks in all are Devonian—the Cambrian in each of them terminates in a sandstone or quartzite member. Such a situation seems very unlikely to have been brought about by subsequent stripping of younger formations. It seems to imply that in the top quartzite of the Cambrian there is preserved a regressive sandstone that lay long at sea level before the advent of the Devonian sea.

The whole Abrigo limestone as here recognized seems to represent a deposit in relatively very shallow water. This is suggested by the numerous intraformational conglomerates, the crossbedding of the sandy layers, and the mud cracks of many of the limy and shaly layers. It is possible that such intercalations of clastic rocks as the Southern Belle quartzite of Stoyanow (1936, p. 477) may represent slight emergence, but it is perhaps equally probable that they, too, are regressive lenses that record lags in the rate of subsidence of the area as compared with the rate of sediment accumulation.

These stratigraphic features suggest that a single sedimentary cycle is represented in the Cambrian of this general area, with the Bolsa (and Coronado) quartzites representing the transgressive phase of marine invasion and the Peppersauce sandstone of Stoyanow and other clastic rocks at the top the regressive phase.

Stoyanow's (1936, p. 478) correlation of the Troy quartzite with the Bolsa implies that the depositional basin extended at least as far north as the Sierra Ancha. The thinning of the beds intervening between the Troy quartzite and the overlying Devonian that occurs north of the Santa Catalina and Little Dragoon Mountains is almost surely due to the later erosion of beds equivalent to the Abrigo, which formerly extended in greater thickness far to the north. Such erosion seems not to have affected the rocks in this area.

PRE-UPPER DEVONIAN UNCONFORMITY

Silurian, Lower and Middle Devonian rocks have not yet been recognized in southeastern Arizona, and the Ordovician, though definitely present at Morenci (Lindgren, 1905, p. 65–66), and Dos Cabezas (Gilbert, G. K., 1875, p. 511–513; Darton, 1925, p. 53; Stoyanow, 1936, p. 478) is not now represented farther to the south within this area. Its western extent is somewhat uncertain because of the doubtful reference of some unfossiliferous beds in the main range of the Dragoon Mountains to the Abrigo limestone.

That the Ordovician rocks never extended into the Bisbee and Tombstone area seems very likely. As mentioned above, the Abrigo becomes increasingly sandy in its upper part and terminates in a bed most likely representing a regressive sandstone that is found not only in these southerly areas but in the main Dragoon Mountains. Its persistence furnishes a strong suggestion that the area where it is represented was essentially at sea level from Late Cambrian time until the encroachment of the Late Devonian sea. If the Ordovician had formerly blanketed the Abrigo, it might well have preserved such a surface bed; but the Ordovician could hardly have been completely removed by erosion without at least local channeling of the Cambrian or leaving remnants of the Ordovician blanket, neither of which has been found.

DEVONIAN SYSTEM

UPPER DEVONIAN SERIES

MARTIN LIMESTONE

NAME

The Martin limestone was named by Ransome from the type locality at Mount Martin in the Bisbee district (Ransome, 1904, p. 33). Ransome (1916, p. 148) later extended the name to the Tombstone district.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Martin limestone has been recognized in the Mule Mountains, Tombstone Hills, and Dragoon Mountains. In the intricately thrust-faulted areas of the Gleeson and Courtland districts and farther northwest in the Dragoon Mountains, the Martin is relatively inconspicuous, owing no doubt to its high proportion of shale and its thin bedding which seem to have localized slipping within it. It here forms minor thrust blocks, disproportionately small even taking account of the thinness of the formation with respect to the other formations of Paleozoic age.

The formation is also the least resistant to erosion of the rocks of Paleozoic age and nearly everywhere is poorly exposed and largely covered by detritus from the overlying rocks. The normally overlying Escabrosa limestone is one of the great cliff formers of the region, and the Martin usually crops out intermittently along smooth slopes extending up to the cliff. Even where structural disturbance has placed another formation in the normal relative position of the Escabrosa, the Martin commonly has a similar topographic relation.

STRATIGRAPHY

The exposures of the base of the Martin are commonly poorer than those of the remainder of the formation. However, in the small clean outcrops furnished by creek cuts, no discordance between the basal beds and the underlying Abrigo has been detected. In the section measured in the Dragoon Mountains, the base of the Martin is marked by a few feet of conglomerate that contains rounded cobbles of dolomite as much as 6 inches in diameter and quartz pebbles one-fourth of an inch across in a matrix of crossbedded sandstone. The materials could all have been derived from the sandy dolomite of the Abrigo immediately beneath. This was the only exposure seen that suggested the emergence and erosion of the underlying Abrigo in the long interval between its deposition and the encroaching of the Late Devonian sea. Erosion during Ordovician, Silurian, Early and Middle Devonian followed by encroachment of the late Devonian sea upon an irregular topography has been inferred from good evidence at several localities farther north in Arizona.[3]

The Martin is more variable, lithologically, than any of the other formations of Paleozoic age of the area. In the type section, in the Bisbee quadrangle to the south, the formation is dominantly limestone, with some pinkish shale in the lower half (Ransome, 1904, p. 34–35). In the Tombstone Hills, however, the shale with subordinate sandstone constitutes over half the formation. In the Dragoon Mountains sandstone is still more conspicuous, and dolomite is more abundant than limestone, judging from field tests with dilute acid. Although detailed sections were not measured in the Whetstone Mountains, the Martin also appears to be more largely clastic there than it is at Bisbee. Stoyanow (1936, p. 492) points out that the Martin limestone becomes increasingly sandy northward for a long distance.

The following sections illustrate the lithology of the Martin limestone in the Tombstone Hills and Dragoon Mountains.

Section of Martin limestone, Tombstone Hills one-half mile southeast of Ajax Hill (fig. 3, sec. 2)

	Feet
Escabrosa limestone:	
Limestone, light-gray, weathers dark gray, crystalline, sparingly fossiliferous	6
Martin limestone. No evidence of discordance at contact.	
1. Shale, gray, limy, ranges to shaly sandstone, poorly exposed	28
2. Concealed, probably shale or thin-bedded limestone	17
3. Limestone, gray, in part dolomitic, crystalline, massive, contains partly silicified fossils, forms ledge	13
4. Sandstone, gray, weathers greenish gray, limy, with sporadic chert nodules and some nodular masses of milky quartz up to 3 inches in diameter, thin bedded at base (1 inch) becomes thicker bedded (1 foot) at top, and ranges to sandy limestone; weathers slightly buff in places; forms a slope	25
5. Chert, massive, black	3
6. Concealed	3
7. Chert, black	½
8. Limestone, finely crystalline, dove-colored, weathers conspicuous yellow-brown; highly fossiliferous; forms ledge	1½
9. Shale, thin parting	½
10. Chert, dark-gray, weathers with a white crust	½
11. Shale, sandy, gray, weathers buff, poorly laminated; contains chert nodules up to 2 inches thick and toward top some fairly continuous chert layers 1 inch thick	24½
12. Limestone, gray, cherty and becomes nearly all chert on top surface, fossiliferous	½

[3] Anderson, C. A., and Creasy, S. C., oral communication regarding the Prescott area, April 1952; Peterson, N. P., oral communication regarding the Globe area, April 1952.

Martin limestone—Continued	Feet
13. Shale, gray	1½
14. Limestone, blue-gray, fine-grained, massive, fossiliferous; forms a ledge	4
15. Limestone, nodular, with shale partings; beds 2–12 inches thick; highly fossiliferous; forms a bench in the topography	11
16. Limestone, blue-gray, weathers darker and with irregular brown mottling; beds 2 inches to 1 foot thick; fossiliferous	3
17. Limestone, sandy, crossbedded, brownish gray, weathers flat gray, gradational with member 16	1½
18. Shale, weathers tan, nodular, poorly bedded, slightly blocky	7½
19. Shale conglomerate with small chert pebbles	½
20. Sandstone, very limy, contains quartz granules about one-fifth of an inch across; highly fossiliferous	1
21. Shale, gray, thin-bedded, somewhat blocky, with a few limestone beds 2–3 inches thick, some lime concretions that become more conspicuous upward	21
22. Limestone, calcite nodules up to 2 inches across; many small crinoid stems and brachiopods	½
23. Shale, gray, thin, platy, very limy, slightly sandy	4
24. Limestone, blue-gray; highly fossiliferous; very thin bedded at base, beds up to 9 inches thick at top	3½
25. Shale, thin-bedded, yellowish to brownish, somewhat limy and sandy, some thin limestones toward the top	13
26. Limestone, blue, mottled with brown, massive, highly fossiliferous, many brachiopods and small cup corals; forms a low cliff	14
27. Limestone, blocky, thin-bedded (½ inch) at base, thicker (6 inch) beds at top	7½
28. Sandstone, shaly and limy	1
29. Chert, blocky, brecciated	1
30. Sandstone, gray, shaly	½
31. Shale, gray, weathers buff, and interbedded thin limestone, slightly sandy	6
32. Sandstone, limy, massive ledge	1½
33. Limestone, weathers reddish to buff, shaly and sandy, thin sandstone interbeds	9
Total Martin limestone	229½

Apparent conformity.
Abrigo limestone:
Quartzite 4 feet thick at top.

Section of Martin limestone, Dragoon Mountains, 2¼ miles south of Black Diamond Peak (fig. 3, sec. 3)

[Continuation of section on pages 17 and 18]

Escabrosa limestone:	Feet
Massive crinoidal limestone, not measured.	
Martin limestone:	
1. Dolomite, dark-gray to yellow-brown and buff; beds 1–4 feet thick, average about 2 feet; few fossils	20
2. Shale at base; passes upward into a massive buff dolomite; highly fossiliferous	48
3. Dolomite, pinkish-gray, weathers buff; massive; silicified corals plentiful	32

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Martin limestone—Continued	Feet
4. Limestone, blue, mottled with buff; subordinate interbedded brown-weathering sandstone; fossils	35
5. Dolomite, sandy, and blue limestone, interbedded in beds about 2 feet thick; locally a little quartzite	39½
6. Sandstone, weathers brown; crossbedded, dolomitic, a little shale toward the base; somewhat silicified toward top where white chert nodules up to 2 feet in diameter occur	44
7. Shale, brown, laminated, a few 6-inch beds of sandstone	6
8. Sandstone, gray-brown, some mottled sandy dolomite; massive; fossils	50
Total Martin limestone	274½

Abrigo limestone:
Conglomerate, with rounded boulders of dolomite up to 6 inches in diameter in matrix containing well-rounded quartz granules up to one-third of an inch in diameter. Top of member 1 of section on page 17.

Section of Martin limestone, Little Dragoon Mountains, 1½ miles northeast of Seven Dash Ranch house (fig. 3, sec. 4)

Escabrosa limestone:	Feet
Basal bed here a massive crinoidal dolomite.	
Martin limestone:	
1. Concealed, probably shaly limestone	15
2. Limestone, shaly, pink; soft and forms slope, about	30
3. Dolomite, black; carries colonial corals (*Syringopora?*)	4
4. Concealed	10
5. Dolomite, very light-gray; microcrystalline at base; becomes sandy upward	50
6. Dolomite, buff, dense, microcrystalline; carries quartz inclusions about 1 inch in diameter. Problematical fossils	10
7. Shale, limy, and limy sandstone and sandy dolomite; alternating thin beds (½ inch); *Atrypa reticularis*	84
8. Sandstone, brown, grades into member 7	18
9. Dolomite, dense, pinkish-gray at base, weathers yellow (not buff); contains sporadic calcitic beds ½–2 feet thick; grades upward into dense gray dolomite; lower part contains quartz masses resembling silicified corals	55
Total Martin limestone	276

Abrigo limestone:
1. Quartzite, composed of well-rounded grains of quartz, jasper, and black chalcedony about 1 mm in diameter; massive at base but thinner bedded toward top.

The upper contact of the Martin in the Bisbee district has been described by Ransome (1904, p. 34–35) as difficult to fix accurately owing to resemblance of the upper beds to the basal Escabrosa. Similar difficulty was experienced in the northwestern part of the Mule Mountains in the area of this survey, but farther north there is generally a shale or sandstone at the top of the

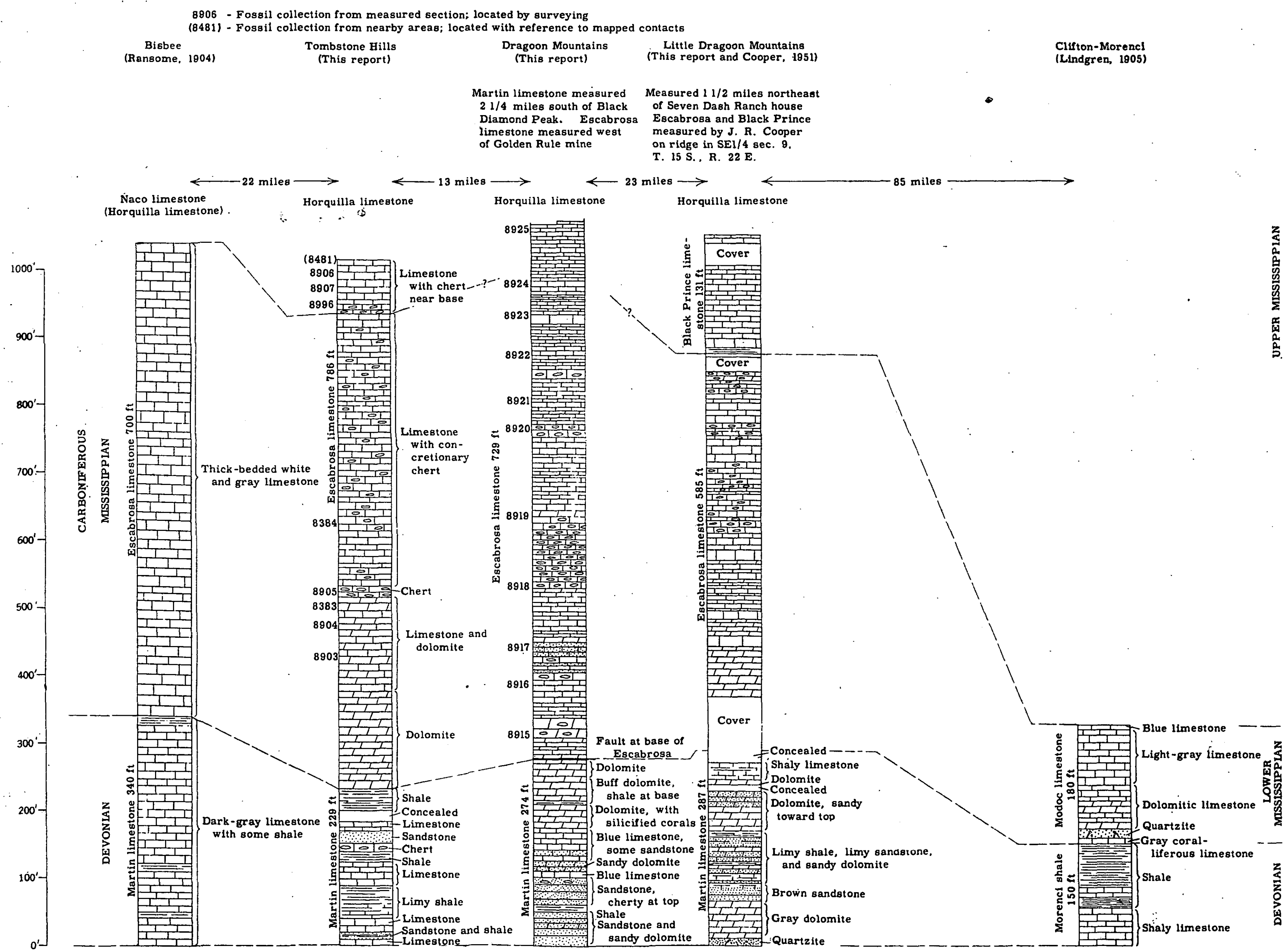

FIGURE 3.—Correlation of some Devonian and Mississippian sections in southeastern Arizona.

Martin upon which rests a basal Escabrosa of greatly contrasting lithology. The contact is relatively definite, although talus from the overlying Escabrosa conceals it for long distances.

The Martin limestone, as has been mentioned, is a formation relatively weaker than its neighbors and thus is commonly much more sheared and thinned in zones of intense deformation than they. Nevertheless, its variable lithologic character and alternating beds of clastic and nonclastic material are distinctive features. Furthermore, the Martin is abundantly fossiliferous; and even in zones of shearing the characteristic silicified corals can commonly be recognized. And despite its generally poor exposures the Martin is rather certainly distinguishable from all other formations with the possible exception of the doubtfully Cambrian rocks at the top of the Abrigo as mapped and measured along the west flank of the Dragoon Mountains.

In areas of contact metamorphism the Martin is generally much more widely affected than the overlying Escabrosa and in this respect is comparable to the Abrigo. Its dolomitic and sandy and shaly strata are ideally constituted for the production of metamorphic minerals, but they retain their bedded character even where highly altered. Thus, the alternation of different varieties of hornfels forms a feature that permits rather confident assignment of these rocks to the Martin. The underlying Abrigo is generally much more finely banded, and hornfels derived from it still retain clues of the edgewise conglomerates, mud-cracked limy shales, and shaly sandstones that render their distinction from the Martin easy even in areas of intense metamorphism.

THICKNESS

At Bisbee the Martin limestone was measured by Ransome (1904, p. 33–34) at 340 feet. Although he gave the same thickness for the Martin at Tombstone (Ransome, 1916, p. 148), the detailed measurement of this survey shows only 229½ feet. Check measurements made nearby with a planetable revealed 234 feet. In the section measured on the west side of the Dragoon Mountains, the beds assigned to the Martin are about 275 feet thick, in the Little Dragoon Mountains 276. The variations in thickness do not appear significant of regional thinning. (See fig. 3.)

CONDITIONS OF DEPOSITION

The Martin limestone in this area appears to represent a shallow sea deposit. The increasing proportion of clastic sediments toward the north strongly suggests a land mass in this general direction as a source of its sediments. This also is the interpretation of Stoyanow (1942, p. 1265–1271).

AGE AND CORRELATION

The fauna of the Martin limestone from the Bisbee quadrangle was discussed exhaustively by H. S. Williams (Ransome, 1904, p. 35–42), who correlated it with the base of the Chemung of the New York section (Upper Devonian) though also with the Middle Devonian of Russia. As pointed out by Kindle (1919, p. 46) and Stoyanow (1936, p. 486–487), the first correlation is the correct one. The Martin is definitely Upper Devonian.

The Martin limestone correlates, without much question, with the Morenci shale of the Morenci district (Williams, 1905, p. 69; Stoyanow, 1936, p. 494). The Percha shale of New Mexico seems to be younger. The Martin is recognized as far north as the Roosevelt Dam on the Salt River (Ransome, 1916, pl. 35), although Stoyanow (1936, p. 489–492) regards the upper part of the formation, as it was delimited by Ransome, to be younger than the type Martin. Stoyanow has also emphasized the increasing proportion of clastic rocks in the Martin toward the north.

POST-MARTIN–PRE-CARBONIFEROUS DISCONFORMITY

The Escabrosa limestone, of Mississippian age, rests upon the Martin limestone with no measurable structural discordance nor obvious erosional features. The Martin is not of latest Devonian age, so that there is a time break present. There is no direct evidence as to whether higher Devonian rocks were deposited in this region and removed by erosion prior to the advent of the Escabrosa sea or whether the area was emergent throughout this interval. The overlying Escabrosa limestone contains a fauna of Kinderhook affinities (Girty 1904, p. 46–54), so that its deposition began early in Mississippian time though not quite at the opening of that epoch as usually understood.

MISSISSIPPIAN SYSTEM

EARLY AND MIDDLE MISSISSIPPIAN

ESCABROSA LIMESTONE

NAME

The Escabrosa limestone was named by Ransome (1904, p. 42) from Escabrosa Ridge in the Bisbee quadrangle.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Escabrosa limestone crops out in the north end of the Mule Mountains, at the south edge of this area, where it forms prominent cliffs on both sides of Tombstone Canyon near its mouth. Tombstone Canyon, Mule Mountains, is drained by the stream entering the mapped area half a mile east of the common south corner of the Pearce and Benson quadrangles and thence trends almost northwest toward Lewis Springs. A few small outcrops are found in the flat a mile or two farther north and also in the thrust zone at the north foot of the Mule Mountains 2 miles north of Gadwell Spring.

In the Tombstone Hills the Escabrosa forms a prominent northward-trending ridge about 2 miles long, lying east of Ajax Hill, and also crops out in an anticlinal axis on the east end of the north ridge of the hills.

In the Gleeson district and near Courtland, the Escabrosa forms many fault blocks, several of rather large size. Slices of the formation also occur along the thrust at Barretts Camp and a mile northeast of South Pass. The principal outcrops of the Escabrosa are in the main ridge of the Dragoon Mountains. It extends practically continuously, although as several separate thrust masses, for several miles northward from a point on the east flank of the range about a mile north of South Pass. It crosses the ridge and for most of this distance crops out high on the southwest slope. Several smaller blocks of Escabrosa limestone are found at the southwestern foot of the Dragoon Mountains northwest of South Pass. Northwest of Black Diamond Peak the Escabrosa occupies wide areas and caps several high peaks on the western divide of the range. It also is prominent near China Peak and still farther north forms a nearly continuous band across the range near Cochise Stronghold. Minor masses of the formation occur south of Fourr Ranch and in Jordan Canyon, near the north boundary of the Benson quadrangle.

The Escabrosa limestone is one of the formations most resistant to erosion. The lower, more massive part, in particular, forms impressive cliffs that are only slightly less prominent than those of the Bolsa quartzite. These massive beds also weather into great rounded forms unlike any developed on the thinner bedded limestones of the rest of the stratigraphic section. The upper, more thinly bedded part of the Escabrosa is not distinguished topographically from much of the overlying Naco group.

STRATIGRAPHY

The base of the Escabrosa limestone is generally not well exposed because of the weakness of the underlying Martin limestone and the consequent accumulation of talus. However, above this talus the barren cliffs of Escabrosa offer practically complete exposure of the massive part of the formation, while the thinner upper beds are also, as a rule, fairly well exposed on dip slopes.

As pointed out by Ransome, the characteristic rocks of the formation are white to light-gray coarse granular limestones, commonly composed mainly of fragments of crinoid stems. Toward the base of the formation, the beds are generally 10 to 20 feet thick; and though they are somewhat thinner in the middle of the formation, they form practically an unbroken slope, as a rule, to within a few score feet of the top. There are a few beds of dense dark-gray limestone in the lower part of the formation, but such rocks are subordinate except near the top. These dense rocks are generally gray on fresh fracture, in contrast to the generally pink tints on fresh fracture of the overlying Horquilla limestone. However, there are a few beds of fine-grained limestone that is pink on fresh fracture near the top of the formation as mapped, so that the boundary with the Horquilla limestone is generally difficult to draw. Lithologically, the beds in the top hundred feet of the Escabrosa resemble the Horquilla rocks more than they do the lower, main part of the Escabrosa. These thin beds may possibly be equivalent to the Black Prince limestone (Gilluly and others, 1954) (upper Mississippian) of the Little Dragoon Mountains. But the fossils from this area are not diagnostic of late Mississippian age; and in the absence of a clastic or other distinctive member at the base, the discrimination of a contact, if one exists, would hardly be feasible.

Neither sandstone nor shale have been found in this formation. Chert is absent in the lower part, but a few thin bands occur in the middle, and toward the top, nodular chert is common. In the Bisbee area Ransome (1904, p. 43) described the Escabrosa as essentially free from dolomite. Field tests with dilute acid have shown considerable dolomite in the lower massive part of the formation in the Tombstone Hills and Dragoon Mountains, though the formation is dominantly calcitic.

As mentioned by Ransome, the contact with the basal member of the Naco (Horquilla limestone, of this report) is not readily detected by study of the lithology. In unfaulted fossiliferous sections the base of the Pennsylvanian, as determined by the fossils, comes in the first weak zone above the cliff-forming part of the Escabrosa. This is true on Military Hill and half a mile southeast of Ajax Hill in the Tombstone Hills, and in the Bisbee district north of Don Luis, as determined by Dr. James Steele Williams. The boundary in the Tombstone Hills is probably essentially correct as drawn on pl. 5, because the structure is simple enough to permit rather confident tracing of even faint lithologic differences. However, in the much-faulted and highly disturbed area of the Dragoon Mountains and its southeastern outliers near Courtland and Gleeson, it is practically certain that some of the thin-bedded rocks of the upper Escabrosa have locally been mapped on plate 5 as Horquilla limestone. It is probable that such errors are not many nor are they of great structural importance, but they almost surely exist.

The only fossils common in the lower part of the

Escabrosa limestone are some cup corals and the crinoidal fragments of which the rock is largely composed. Some of these cup corals are more than 18 inches long—much larger than any seen in the Naco group during this survey. Higher in the formation, other fossils, especially brachiopods, are relatively much more abundant.

The following section was measured in the Tombstone Hills on the west slope of the ridge east of Ajax Hill. It includes only a little more than the lower half of the Escabrosa limestone.

Lower part of Escabrosa limestone, east of Ajax Hill

	Feet
Escabrosa limestone:	
1. Limestone, dark-blue-gray, in beds 6–12 inches thick; a little nodular chert at base, more evenly layered thin (2–3 inch) chert beds upward; very fossiliferous toward top, fossil coll. USGS 8384, less fossiliferous at base, fossil coll. USGS 8383	106
2. Limestone, dark-blue-gray, almost undistinguishable in appearance from member 3; a few thin sandy streaks, but thick bedded	30
3. Dolomite, dark-blue-gray, massive, grades upward into member 2	8
4. Limestone, blue-gray, massive above but in 2-inch beds toward base; thin zone of ripple-marked sandy limestone and edgewise conglomerate at base	72
5. Limestone, blue-gray, thick-bedded (5 feet or more)	8
6. Limestone, gray, massive, granular, in thick beds, indistinct partings; a few thin layers of rusty-weathering chert; many cup corals	20
7. Dolomite, gray, massive, crinoidal; discontinuous chert layers 2 inches or less thick commence about 10 feet above base and occur at intervals to top; resembles member 6 very closely	19
8. Limestone, light-gray, coarsely granular, massive, closely resembles member 9	23
9. Dolomite, gray to blue, chiefly gray; very massive; largely crinoidal; weathers with notably pitted surfaces; fossiliferous	55
Total	382
Martin limestone:	
Limestone, blue-gray, poorly exposed	15

A less detailed section of the entire Escabrosa limestone was measured half a mile farther south. It is a continuation of the section of the Martin limestone given on pages 26–27.

Section of Escabrosa limestone, half a mile southeast of Ajax Hill, Tombstone Hills (fig. 3, sec. 2)

	Feet
Horquilla limestone:	
Limestone, thin-bedded, chiefly gray, slightly pink on fresh fracture, in beds 1 foot or less thick, more bluish gray toward top fracture; fossiliferous.	
Escabrosa limestone:	
1. Limestone, dense, microcrystalline, chiefly gray but with pink cast on fresh fracture; considerable chert with pseudobreccia structure near base, beds 2–20 inches, average 6 inches thick; fossil coll. USGS 8907 from middle, USGS 8906 from base	79
2. Limestone, gray with faint-pink cast on fresh fracture, in beds 6–18 inches thick; much concretionary chert in thin nodules along bedding; forms steep cliff	313
3. Limestone, light-gray, thin-bedded (6–18 inches), with much nodular concretionary and bedded chert that weathers brown; forms slope	160
4. Limestone, and dolomite, very dark-gray, thick-bedded; forms conspicuous cliff; fossil coll. USGS 8905	40
5. Dolomite and limestone, thick-bedded but less massive than member 4; zone about 10 feet thick at base contains chert in 3 or 4 thin bands 1–4 inches thick separated by 1- to 2-foot limestone beds; chert weathers brown and tan; fossil coll. USGS 8904 and 8903	102
6. Dolomite, gray, coarsely crystalline; many crinoid fragments; in beds 2–6 feet thick	146
Total	786
Martin limestone:	
Shale, gray, limy; ranges to shaly sandstone, poorly exposed (member 1 of section on page 26)	28

On the mountain spur west of the Golden Rule mine, about 3 miles north of the area shown in plate 5, the Escabrosa limestone is well exposed. The base may be faulted out as the Escabrosa rests in obvious fault contact upon Abrigo limestone.

The following section was measured at this locality—the only one in the Dragoon Mountains that seems to offer a nearly complete exposure.

Section of Escabrosa limestone northeast spur of Dragoon Mountains, west of Golden Rule mine (fig. 3, sec. 3)

	Feet
Horquilla limestone:	
Limestone, chiefly medium-grained, crinoidal, subordinate light-gray fine-grained beds; pink, weathers medium to light gray; average bed about 3 feet, ranges from 8 inches to 6 feet.	
Conformable contact.	
Escabrosa limestone:	
1. Limestone, locally dolomitic, lenticles of brown-weathering chert; beds 2–4 inches; a few 3-foot ledges of massive dark-gray limestone; forms smooth slope broken by low ledges, but along strike forms steep cliff; fossil coll. USGS 8924 from about 16 feet below top	54
2. Limestone, light-gray, ranges from coarsely crinoidal to dense; massive, forms strong ledge; fossil coll. USGS 8923 from about middle	19
3. Limestone, blue-gray, finely crystalline to aphanitic, with many crinoid fragments; beds average less than 1 foot thick, but a few 3- to 6-foot massive ledges of limestone with subordinate chert; gray, weathers to slight pinkish cast	51

Escabrosa limestone—Continued	*Feet*
4. Limestone, blue-gray, massive, forms ledge; fossil coll. USGS 8922 from top	5
5. Limestone, generally fine-grained but some coarse crinoidal layers; beds 6 inches to 1 foot thick; light-gray, weathers gray with pink cast	10
6. Limestone, massive; contains irregularly branching chert nodules; forms strong ledge	20
7. Limestone, beds 6 inches to 2 feet thick, some pink, dense, weathers light pinkish gray; some coarsely crinoidal, weathers light gray; sporadic lenticular cherts up to 2 inches thick; forms gentle slope broken by low ledges; fossil coll. USGS 8921 from 15 feet above base	58
8. Limestone, dolomitic, dense, light-gray, weathers yellowish on upper surface; forms ledge	2½
9. Limestone, gray, thin-bedded, poorly exposed	4
10. Limestone, pinkish, dense, slightly dolomitic toward top; forms strong ledge	5
11. Limestone, dense, weathers very dark gray, beds average about 8 inches thick; many short chert lenses; fossil coll. USGS 8920 at base	15½
12. Limestone, dark-gray, finely crystalline, with 3 or 4 thin continuous bands of chert; forms strong ledge	7
13. Limestone, medium- to pinkish-gray, weathers to dull gray; chiefly finely crystalline, sporadic coarse crinoidal beds; beds 2–4 feet thick; forms slope broken by low ledges	104
14. Limestone, dolomitic, dark-gray, very finely crystalline; in beds 2–8 inches thick, weathers to platy fragments	15
15. Limestone, massive, crinoidal, lenticular chert nodules; a single conspicuous ledge; fossil coll. USGS 8919 from top	3
16. Limestone, irregularly mottled with buff dolomitic beds about 6 inches thick; chiefly finely crystalline with faint-pink cast, weathers medium gray to almost black; a few coarse crinoidal beds; a little black and brown chert in fairly continuous thin layers; thinner bedded toward top; fossil coll. USGS 8918 from base	106
17. Dolomite, finely crystalline; pinkish-gray, weathers buff gray	3
18. Limestone, dense, light-pinkish-gray, weathers medium gray; beds 2 inches to 3 feet thick; average about 8 inches	45
19. Limestone, dense to coarsely crystalline, crinoidal; weathers medium gray, with locally a slight purplish cast; a few beds of buff dolomite near middle of member; indistinct bedding, averages about 1 foot in thickness	15
20. Limestone, dark- to light-gray, weathers light gray; interbedded with sporadic thin beds of dense brown-weathering dolomite and discontinuous sandy limestone; fossil coll. USGS 8917 from base	15
21. Limestone, sandy, poorly exposed; weathers to thin chips except for a single 4-foot massive ledge	48
22. Limestone, light-pinkish-gray to light-gray, weathers gray with a faint pinkish cast, varies to blue gray; contains chert nodules ½–2 inches thick, contorted	10
23. Limestone, medium- to dark-gray, weathers gray to buff; poorly exposed, thin-bedded, 8 inches; fossil coll. USGS 8916 from top	50
24. Dolomite, light- to medium-gray, weathers dark gray to black; massive, finely crystalline, mottled with sporadic nodules of white and orange chert	30
25. Dolomite and limestone in beds about 2 feet thick; somewhat brecciated; fossil coll. USGS 8915 from top	34
Total exposed Escabrosa limestone	729

Fault contact (Martin limestone faulted out).
Abrigo limestone.

METAMORPHIC FACIES

Except locally, near the Schieffelin granodiorite in the Tombstone Hills, the Escabrosa has been very slightly metamorphosed in both the Tombstone Hills and the part of the Mule Mountains within the area of this survey. At the south end of the Dragoon Mountains, too, the metamorphism of the Escabrosa has been slight, and in all these areas the formation can readily be recognized by its coarse grain, abundant crinoidal fragments, and generally thick beds, as well as by its stratigraphic position. In the more northerly parts of the area, however, the dynamic metamorphism of all the formations has been considerable, and the superposed thermal metamorphism has in many places produced rocks that can be correlated with their unmetamorphic equivalents only with difficulty or not at all. Generally some hints as to these correlations can be obtained by a study of the progressive alteration of the rocks toward the area of intense metamorphism, but the numerous faults prevent continuous tracing and render uncertain such features as superposition and thickness as clues to stratigraphic position.

In areas where the rocks have been strongly sheared, the higher formations of the Carboniferous lose their generally bluish, tan, or pinkish hues and become a gray or white that approaches that of the normal Escabrosa. However, the coarse grain of the Escabrosa is commonly persistent, and its content of shaly partings is much lower than those of other formations, so that in general one can assign beds to the Escabrosa even in highly sheared sections if a thickness of as much as 50 feet is exposed. Marbleized beds of the Horquilla or Colina are generally finer grained and show remnants of shaly partings which permit their distinction, although locally there are considerable uncertainties and it has been necessary to map some of the rocks in the neighborhood of Middlemarch as undifferentiated Paleozoic.

The relative purity of the Escabrosa as a carbonate formation is generally reflected in the thermally metamorphosed parts of the area. In many places where adjacent formations are hornfels, it is simply marmarized. In areas of slight additive metamorphism, the generally subordinate masses of hornfels derived from the Escabrosa are composed of wollastonite or of tremolite, diopside, and grossularite, depending on the nondolomitic or dolomitic character of the particular bed and the intensity of the metamorphism. These minerals are the same as those formed during the metamorphism of other of the carbonate rocks of the region, but their relatively uniform distribution and the lack of relict stratification in the hornfels is in contrast with the arrangement of the "contact" minerals in the other formations. Most of the other carbonate rocks contain layers of clay or sand which, on metamorphism, give rise to bands of epidote, feldspar, or quartz that mimic the original sedimentary banding. Accordingly, in sections of hornfels 50 feet or so thick, it is generally possible to find relicts of features or of stratigraphic sequences that are characteristic of one or the other of the carbonate formations. Relatively uniform hornfels with no such bands in sections of this or greater thickness have thus been mapped with fair confidence as Escabrosa. The subordinate chert layers of the Escabrosa are commonly altered to bands of wollastonite in which the original long lenticular forms are fairly well preserved and thus differ from the discrete nodular aggregates of wollastonite found in the hornfels of the Horquilla limestone.

Where the additive metamorphism has been considerable, the original features of the rocks are still further obscured and the uncertainties of correlation further increased. Thus, the huge sprays of hedenbergite in crystals a foot long found in the hornfels that is referred to the Escabrosa on Mount Glen have destroyed all features of diagnostic stratigraphic value, and the assignment is made only because the rocks can be traced laterally, with gradually decreasing metamorphism, into marble beds characteristic of the Escabrosa. For the most part, additive metamorphism of such intensity has not affected very large volumes of rock, and uncertainties due to it are not serious.

CONDITIONS OF DEPOSITION

The Escabrosa is so dominantly calcareous, with almost no sandy or shaly components, that it must have been deposited in clear water. The local occurrence of crossbedding and intraformational conglomerate testifies, however, to relatively shallow water during its deposition.

AGE AND CORRELATION

The Escabrosa limestone has been classified by Girty as lower Mississippian, containing correlatives of the Kinderhook and Osage groups and probably of the Meramec group also (Girty, 1904, p. 46–50). Fossils from this area collected during this survey have been identified by the late G. H. Girty and James Steele Williams, and Mr. Williams has supplied the following report.

PALEONTOLOGY OF THE ESCABROSA LIMESTONE

By James Steele Williams

Lists of fossils from all collections listed in the stratigraphic sections are given in a paper by James Gilluly, John R. Cooper, and James Steele Williams (1954), and only several especially significant collections are therefore given here.

The Escabrosa collections consist largely of brachiopods, but one or more corals occur in nearly every collection, and some few collections are exclusively corals. Gastropods and pelecypods are few and poorly preserved and do not contribute to age determinations. The same is true of the bryozoans, which seem to have been practically overlooked in the collecting. They are, however, probably a minor element in the Escabrosa fauna. A few trilobites were collected from one locality (8905), and these belong to undescribed species that, however, are said by J. Marvin Weller, who examined them, to be "pygidia of lower Mississippian type." Weller has not finished a study of lower Mississippian trilobites and so could not suggest identification.

Crinoid columnals are very common in the collections; and in a collection from near the base of the Escabrosa in the nearby Dragoon quadrangle, Edwin Kirk, of the Geological Survey, identified a crinoid calyx as *Agaricocrinus*, which he states is of early Burlington age.

A representative Escabrosa collection came from locality 8905 near Ajax Hill, Tombstone district (member 4 of stratigraphic section on p. 31). This collection consists of the following:

Triplophyllites? sp. A.
Fenestella sp. 2
Camarotoechia metallica (White)
Spirifer centronatus Winchell
Spirifer? sp. indet.
Schuchertella? cf. *S. chemungensis* (Conrad)
Chonetes sp. indet.
Linoproductus gallatinensis (Girty)
"*Productus*"? sp. undet.
Rhipidomella thiemei (White)
Punctospirifer subtextus (White)

Reticulariina? sp. undet.
Pelecypods, 2 or 3 species, undet.
Trilobite, two pygidia, "lower Mississippian type"

Another representative collection came from locality 8384 nearby. It contains—

Empodesma? sp. indet.
Triplophyllites? sp. A.
Spirifer centronatus Winchell
Spirifer centronatus Winchell var. A.
Brachythyris cf. *B. peculiaris?* (Shumard)
Dictyoclostus arcuatus? (Hall)
Rhipidomella thiemei (White)

The brachiopods in these collections are mainly forms found in the Madison limestone and other formations, including the Escabrosa of nearby areas, which are generally considered to be in part of Osage and in part of Kinderhook age.

Regarding the Escabrosa corals, Helen Duncan states (memo., 1947)—

> Corals are not very abundant in these collections. All specimens are fragmentary and some are very poorly preserved. Generic identifications are therefore doubtful, but it was possible to distinguish certain types of rugose corals that seem to be characteristic of the formation. The most common species, which occurs in four or probably five collections, is a small horn coral designated *Triplophyllites?* sp. A. This species is specifically different but closely related to *Menophyllum excavatum* Girty, which is rather diagnostic of Madison limestone faunas. Other less common zaphrentoid corals are referred doubtfully to *Rotiphyllum* and *Empodesma*. A few caninoid corals were found. These seem to belong to the species group of *Caninia cornucopiae* Michelin which is characteristic of the lower Carboniferous of Europe. Only one specimen is sufficiently adequate to compare with *Caninia arcuata* Jeffords, described from the lower Missippippian Lake Valley limestone of New Mexico.
>
> The column-bearing lophophyllid corals and tabulates that are characteristic of the Pennsylvanian and Permian formations in the area are absent from our collections of lower Mississippian age.

Collections made near the top of the Mississippian at two localities suggest the possibility of the presence of beds of Meramec age or younger, which correspond approximately in age to part of the Paradise formation of Stoyanow of the Chiricahua Mountains and probably to part of the Black Prince limestone in the Dragoon quadrangle to the north. In other places faunas thought to be of Osage age immediately underlie the Pennsylvanian. The faunules from the localities of probable upper Mississippian rocks are somewhat contradictory, for species all but characteristic of older zones occur with species generally found in Meramec and younger rocks. The problem is further complicated by the fact that many of the species, as indicated in the lists, cannot be positively identified either because of insufficient material, incomplete specimens, or lack of adequate data about species variation and their ranges in time.

One collection tentatively referred to Meramec age came from locality 8906 near Ajax Hill (see member 1 of stratigraphic section on p. 31). This collection contains the following forms:

Spirifer centronatus? Winchell
cf. *S. pellanensis* Weller
Linoproductus altonensis? (Norwood and Pratten)
gallatinensis? (Girty)
"Productus"? sp. indet.
Rhipidomella burlingtonensis (Hall)
Punctospirifer? sp. undet.
Dielasma? cf. *D. burlingtonensis* (White)
Pelecypods, 2 or 3 species, undet.
Ameura? or a closely related trilobite

Although *Spirifer centronatus?* Winchell is questionably identified in the above collection and although this species is generally characteristic of the Madison limestone, it has been found in beds of Meramec age or younger in the West.

Dr. Weller identified the trilobite listed as *Ameura?* or a closely related form. Regarding these forms he states (written communication, March 7, 1947)—

> These specimens are poorly preserved, but they show characters that I do not recall seeing in any but one Mississippian species, and I think that they are different from that Chester form. In some ways they suggest comparison with small individuals of Pennsylvanian *Ameura*.

Another collection (No. 8907), made near Ajax Hill, from the same stratigraphic section as 8906, but from slightly higher beds contains the following:

Spirifer centronatus? Winchell
Spirifer cf. *Spirifer leidyi* Norwood and Pratten
"Productus"? sp. indet.

From another part of the area, several collections again suggest but do not give conclusive proof of the presence of beds of Meramec age or younger. The assemblages from two collections made within a few feet stratigraphically of each other and from the same section south of Tombstone Canyon, Mule Mountains are here listed.

Collection 8908, the lowest stratigraphically, contains the following:

Fenestella sp. 1
sp. indet.
Spirifer centronatus Winchell
cf. *S. pellaensis* Weller
Chonetes cf. *C. illinoisensis* Worthen
Marginifera? sp. undet.
Linoproductus tenuicostus (Hall)
sp. undet.
"Productus"? sp. indet.

Collection 8909 contains two species: *Composita humilis* (Girty) and *Linoproductus tenuicostus* (Hall).

The first is more characteristic of the Madison limestone fauna, whereas the second is characteristically of St. Louis age, but both are generalized types that are closely related to and may overlap other species.

Collection 8481, also from Tombstone Canyon, Mule Mountains, contains the following:

Linoproductus altonensis (Norwood and Pratten)
gallatinensis (Girty)
sp. undet.

Collections near the top of the Mississippian in other regions are in general smaller and composed either of forms that cannot be reliably identified because of their incompleteness, of single species on which it is not safe to hazard an age opinion, or of very generalized types that do not furnish reliable age data. There is a slight suggestion that upper Mississippian strata might be present at locality 8924, in the section measured west of the Golden Rule mine. (See member 1 of stratigraphic section given on p. 31.)

As shown by the above lists, the faunules collected during this investigation from beds of possible late Mississippian age are almost wholly of brachiopods. However, one trilobite, the *Ameura?* listed above, and several fragmentary corals, which are not specifically determinate, were found. Crinoid columnals are very common in the collections.

In addition to the collections listed, the following have also been identified:

Coll. 8383, near top of cliff east of Ajax Hill. (See member 1 of stratigraphic section on p. 31.)

Rotiphyllum? sp.
Triplophyllites? sp. A
Spirifer centronatus Winchell
Chonetes sp. indet.

Coll. 8514, from north end of butte in west side of sec. 19, T. 20 S., R. 23 E., north of fault.

Triplophyllites sp. C
Lioclema n. sp.
Camarotoechia? sp. undet.
Cleiothyridia? sp. undet.
Punctospirifer? n. sp. A

Coll. 8913, from a point 3,900 feet north and 1,200 feet east of SW. cor. sec. 33, T. 19 S., R. 25 E.

Camarotoechia metallica (White)

Coll. 8914, from point 2,000 feet north and 2,900 feet west of SE. cor. sec. 17, T. 19 S., R. 25 E.

Triplophyllites? sp. A?
Crinoid stems
Camarotoechia? sp. indet.
Rhipidomella thiemei? (White)
Punctospirifer? sp. undet.

The correlations suggested by Williams are shown graphically in figure 3 and are discussed more fully elsewhere (Gilluly and others, 1954).

MISSISSIPPIAN–PENNSYLVANIAN DISCONFORMITY

In this area no faunules of latest Mississippian age have been recognized; in fact, the youngest faunules collected from the upper Escabrosa as mapped might be early Mississippian, even though local faunules suggest an age somewhat younger (Meramec). There is therefore an hiatus between the Escabrosa and Horquilla limestones at least equivalent to all of Chester time and possibly to an even longer time. Ransome (1904, p. 42–43) and Stoyanow (1936, p. 521) both state, in agreement with the findings during this survey, that no evidence of erosional or angular discordance records this time gap. In the absence of fossils, a more satisfactory division between the two formations would be the top of the massive, cliff-forming member of the Escabrosa.

The suggestion of the uppermost faunules that rocks of Meramac age may be locally present invites consideration of the possibility that the sea in which the Paradise formation (Stoyanow, 1936, p. 508–511; Hernon, 1935, p. 653–696), exposed in the Chiricahua Mountains to the east, and the lithologically different Black Prince limestone of the Little Dragoon Mountains (Gilluly and others, 1954) to the north formerly extended over the area. Both these formations include higher Mississippian rocks, up to perhaps middle Chester in age in the case of the Paradise formation of Stoyanow but perhaps not so young in the case of the Black Prince, but fossil data are uncertain.

The Paradise formation of Stoyanow contains considerable shale. The Black Prince is dominantly limestone but has at its base a shale with local conglomerate lenses, suggested by Cooper to be residual from the erosion of tens or hundreds of feet of Escabrosa. It can be confidently stated that no shales comparable to those of either formation occur in the Escabrosa as mapped in this area. For this reason I am inclined to doubt whether the uppermost Escabrosa of this report does in fact include equivalents of either of these formations, despite the weak suggestions of the faunules. In the first place, it is very likely, as pointed out by Stoyanow (1942, p. 1255–1282), that the upper Mississippian shoreline lay to the west of the Chiricahuas. The area here discussed was thus shoreward from one receiving shale deposition. It thus seems unlikely that only calcareous deposits such as characterize the uppermost Escabrosa would be depositing here while shales were accumulating offshore.

If it is indeed true that all the Escabrosa of this area is of early Mississippian age, the disconformity at its top must represent both the one above and that below the Black Prince in areas to the north. Possibly then, it is an erosion surface left after removal of upper Mississippian strata that formerly extended over the area. In any event, the nearly perfect conformity of beds above and below and the paucity or absence of conglomeratic or other clastic rocks suggest a surface of extremely low relief. It is perhaps equally likely that it remained nearly at sea level throughout the interval from early Mississippian to early Pennsylvanian time, undergoing neither appreciable erosion nor deposition.

PENNSYLVANIAN AND PERMIAN SYSTEMS

NACO GROUP

NAME AND SUBDIVISIONS

In the Bisbee district, Ransome (1904, p. 44–54) defined the Naco limestone as comprising the limestones of Pennsylvanian age overlying the Escabrosa limestone. The thickness was estimated at about 3,000 feet. Fossils from the formation were recognized by Girty (1904, p. 46–54) to fall into two groups: one of earlier Pennsylvanian and one of much later Pennsylvanian age which he compared to the Hueco fauna of west Texas. The Hueco limestone, as now restricted—the upper part of the original Hueco—has been classed as Permian(?) by the United States Geological Survey. Stoyanow (1936, p. 522–523) suggested the restriction of the name Naco to the lower part of the formation as described by Ransome. There is evidence of several faunal divisions in the Naco as originally defined, and there is sufficient lithologic distinction between several parts of the formation to permit their mapping in the area of this survey. Nevertheless, it seems probable that a name will long be useful in southeastern Arizona for the entire assemblage of Pennsylvanian and Permian rocks to which Ransome originally applied the name Naco. I have therefore thought it best to retain Naco as a group term, subdividing the group into formations for this area. There seems to be no more reason to single out the basal part of the Naco as originally described and limit the name to that part than to select any other part. It is probable that the divisions here recognized as formations (that is, as fundamental map units) will not prove useful over a very wide area, so that use for the name Naco in the original wide sense will long persist.

The Naco group is divided in this report into four formations. These are, in ascending order, the Horquilla limestone, the Earp formation, the Colina limestone, and the Epitaph dolomite. In the previous paper by Gilluly, Cooper, and Williams (1954), the Scherrer formation and the Concha limestone are also included in the Naco group and are younger than the Epitaph, but these formations do not crop out in the area of this survey. Graphic sections of these formations are shown in plate 7.

HORQUILLA LIMESTONE

NAME

The Horquilla limestone is named from the exposures on the eastern spur of Horquilla Peak, about a mile southeast of Ajax Hill, in the Tombstone Hills (Gilluly and others, 1954). (See pl. 13.)

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Horquilla is the most widely exposed formation of the Naco group in this area. Its outcrops cover most of the eastern part of the Tombstone Hills, are widespread in the northwestern foothills of the Mule Mountains, at the south part of the map area, and form much of the main ridge of the Dragoon Mountains north of South Pass. They are also plentiful in the Courtland and Gleeson districts, where they are much broken by faults, as well as in the thrust area 2 miles northwest of Gadwell Spring, at the north foot of the Mule Mountains. North of Cochise Stronghold the Horquilla limestone is more widely exposed than any other formation of pre-Cretaceous age.

The Horquilla is much less resistant to erosion than the underlying Escabrosa limestone and in several places forms dip slopes of the cuestas held up by the Escabrosa. However, it is not generally a valley-forming formation but makes gently sloping hills whose relatively smooth contours are interrupted here and there by the outcrop of a thicker, more resistant ledge-forming bed.

STRATIGRAPHY

The base of the Horquilla limestone is an obscure surface of disconformity which has not been identified more closely than within a score of feet, stratigraphically. As mentioned in the description of the Escabrosa there is no marked lithologic boundary and no evidence of erosion during the latest part of the Mississippian period. As closely as it was bracketed by fossil collections, the boundary appears to fall in a zone of thin-bedded limestones that generally weathers to a topographic sag.

Above this dubious basal zone, the Horquilla consists of a series of thin-bedded blue-gray limestones with a few thicker beds, up to 6 or even 8 feet thick. A few beds of reddish-weathering shaly limestone are intercalated in the upper half of the formation as recognized. Most of the limestone is dense and pinkish gray on fresh fracture, but a few scattered beds fail to show the usual pink tinge. Others, especially, the thicker ones, are coarsely crystalline and consist largely of crinoidal fragments, thus resembling much of the Escabrosa limestone.

A feature valuable in discriminating this formation from both the underlying Escabrosa and the overlying Earp formation is the common presence of small fusulinids, rarely, if ever, exceeding 6 millimeters in length and 1–2 millimeters in diameter. The larger fauna is chiefly composed of brachiopods and bryozoans.

The following section, a continuation of the section of the Escabrosa measured on Horquilla Peak, is the type section of the Horquilla limestone.

Section of Horquilla limestone on spur east of Horquilla Peak, Tombstone Hills (pl. 7, sec. at lower left)

[Top of section faulted; from study in conjunction with James Steele Williams of this and the section on the west foot of Colina Hill, where there is an unbroken section through the upper part of the Horquilla to the Earp formation, it is believed that not more than 200 (perhaps less than 50) feet of beds are missing from the top of this section]

	Feet
1. Limestone, thin-bedded (2 feet or less), some with purplish to pinkish cast, mostly gray on fresh fracture; a little nodular chert	41
2. Limestone, massive ledge; fossil coll. USGS 8479	6
3. Limestone, thin-bedded, like member 1 except for absence of purple or reddish cast on fresh fracture	48
4. Limestone, massive ledge	7
5. Limestone, like member 3	22
6. Limestone, aphanitic, gray on fresh fracture, some chert, very fossiliferous; massive ledge with one thin reddish shaly parting near middle	35
7. Limestone, gray, thin-bedded, fossiliferous	43
8. Limestone, thin-bedded below but passes upward to thick, massive ledge at top; fossil coll. USGS 8934 from top	35
9. Limestone, massive, very cherty, with irregular masses of red chert, many spherical, others concretionary and subparallel to bedding; forms ledge	6
10. Limestone, weathers reddish and reddish brown, thin-bedded, platy, current-bedded, very fossiliferous; forms slope	12
11. Limestone, like member 9	6
12. Limestone, like member 10	10
13. Limestone, like member 9	13
14. Limestone, like member 10	170
15. Limestone, light-gray, massive with large chert nodules; makes strong ledge that can be traced for a long distance	9
16. Limestone, shaly, thin platy, pink, weathers buff and red; forms saddle; many bryozoa; fossil coll. USGS 8933 from middle of member	77
17. Limestone, pinkish gray on fresh fracture, chiefly in beds 2–6 inches thick, dense, fossiliferous, cherty, some concretionary chert masses parallel to bedding; few chert nodules show fusulinid casts; few thicker crinoidal beds up to 6 feet thick occur but do not contrast notably in the topography with the thinner beds; fossil coll. USGS 8932 from 180 feet above base	287
18. Limestone, light-gray, pinkish gray on fresh fracture, in beds 2 feet or less thick; much pink-weathering chert, with some irregular masses of nodular black chert up to 6 or 8 inches across; fossil coll. USGS 8387 and 8931 from top; USGS 8386 in middle of member; USGS 8930 and 8385 from base	122
19. Limestone, weathers slightly pink, in beds that are 1 foot or less thick; more bluish gray toward the top; fossiliferous (fusulinids); lower part forms a saddle; mapped as base of Naco group	50
Total Horquilla limestone, exposed	[1] 999

Escabrosa limestone:

Limestone, dense, microcrystalline, chiefly gray on fresh fracture but with some pink, thin-bedded; member 1 of Escabrosa limestone section on page 3.

[1] H. R. Wanless (personal communication, 1949) measured a total of 1,761 feet of beds at this locality between the fault at the top of this section and the base of the Escabrosa limestone. Of this total he assigned 619 feet to the Escabrosa, evidently placing his contact 117 feet below the lowest fusulinids. These figures compare with my measurement of 786 feet of Escabrosa and 999 feet of Horquilla, total 1,785 feet. Evidently very good agreement exists between these independent measurements when account is taken of the different horizons chosen for the top of the Escabrosa.

The contact of the Horquilla limestone with the overlying Earp formation is not ordinarily well defined. Thin pinkish-weathering shales occur in the Horquilla at intervals for a long distance below the top. The base of the Earp formation is arbitrarily chosen at the point where shales become dominant over the limestone. However, the shales evidently localize bedding-plane slippage and are commonly much sheared. In many localities where the Horquilla and Earp are in normal succession, the contact is a fault, commonly of unknown stratigraphic displacement. The distinctive beds of the Earp formation are largely in its upper part, so that it is ordinarily impossible to measure the stratigraphic displacement of these bedding faults. In the area chosen as the type locality of the Earp formation, there is no appreciable faulting at the base; but here, unfortunately, only a few score feet of the Horquilla limestone are exposed below. In the fairly complete exposures at the west foot of Colina Ridge, in sec. 35, T. 20 S., R. 22 E. in the southern part of the Tombstone Hills, such faulting as occurs seems to be within the Earp formation rather than at its base. If this is true, the section given above of the beds on and east of Horquilla Peak probably gives a nearly complete representation of the Horquilla limestone. Incidentally, no place was observed in the area mapped where both top and bottom of the Horquilla limestone occur in measurable sections, undisturbed by faulting. The thickest sections mapped, though not well-enough exposed for detailed measurement, are not more than 1,200 feet in ostensible thickness, suggesting that only about 200 feet of the formation is missing from the section chosen as the type.

That this estimate does not involve gross error is perhaps suggested by the fact that the aggregate thickness of the Naco group measured in this area totals approximately 3,000 feet, essentially the same as the figure arrived at by Ransome (1904, p. 45) in the Bisbee area to the south. In both areas, however, erosion has removed higher beds prior to the deposition of Comanche rocks, and this agreement may be entirely fortuitous. Cooper (Gilluly and others, 1954) has measured 1,600 feet of beds referred by him to the Horquilla limestone in the Gunnison Hills, just north of this area. (See pl. 7, lower right section.) A covered interval equivalent to another 175 feet of strata intervene between the top of this section and the Earp formation, so that the total thickness of the Horquilla in that area is possibly 1,775 feet. Cooper also measured incomplete sections of 1,050 feet and 1,325 feet in the Little Dragoon Mountains and Johnny Lyon Hills, respectively. An estimate of approximately 1,200 feet thickness for the Horquilla in the area of this report seems about as good a one as can be justified from these scanty data, with the uncertainties implicit in the extreme structural disturbance of the entire area mapped.

PETROGRAPHIC FEATURES

The carbonate beds of the Horquilla constitute well over 98 percent of the formation in its characteristic exposures. These beds are almost wholly calcitic, and no true dolomite beds were found anywhere in the formation. They are generally microcrystalline, though there are a few coarsely granular beds composed dominantly of crinoid fragments. The bedding is marked by thin shaly partings, and in places these shaly streaks are as much as 2 or 3 inches thick and might be called limy shale. The shale locally contains fine sand, especially in the upper part of the formation, but a coarse clastic bed has been found in only one locality within the Horquilla limestone. This 2-foot bed is composed of grit and fine conglomerate, which can be traced for a few hundred feet on the north spur of Gleeson Hill. This conglomerate is about 400 feet above the base of the Horquilla and contains pebbles of black chert, as much as 1 centimeter in diameter, subordinate quartz grains that show frosted surfaces, and rounded pebbles of limestone. It is overlain and underlain by normal pink microcrystalline limestone of characteristic Horquilla lithology and is regarded as a merely local feature. The chert of the Horquilla is generally in nodules or irregular masses, unlike most of the few long chert lenses that persist for many feet along the strike in the Escabrosa.

Where the Horquilla has been strongly sheared, it is generally paler, though pinkish streaks and lenses persist in many places even where the formation has been reduced to a schistose marble. Furthermore, it is rather astonishing to find in highly sheared rocks fusulinids that still retain their recognizable punctate character despite having been stretched to lengths as much as twice the original. The chert nodules and masses are also persistent and distinguishable from the broken cherts of the Escabrosa, so that by these features it is generally possible to distinguish the Horquilla from the Escabrosa even in zones of strong shearing. The clastic beds of the Earp and of the Abrigo and Martin are generally recognizable, so that the only formation with which the Horquilla is likely to be confused in such zones of deformation is the Colina limestone. Where the fusulinids are so greatly deformed as no longer to be distinguished, I have been unable to distinguish these two formations; and unless the stratigraphic sequence was unambiguous, the rocks in such localities have been mapped as undifferentiated Paleozoic.

Under thermal metamorphism, the Horquilla limestone has been much more widely altered than the Escabrosa, though not as widely as the Abrigo, Martin, or Earp. The shaly partings and subordinate thin interbeds of shale suffice to give most of the hornfels derived from the Horquilla an aspect decidedly different from those of either the Escabrosa or the Colina. The generally thinner bedding of the Horquilla is commonly preserved by streaks of zoisite, epidote, or orthoclase in the hornfels. The chert nodules are represented by radiating aggregates of wollastonite and diopside. In some specimens grossularite has formed. Where material transfer has been considerable, the hornfels derived from the Horquilla contains andradite, biotite, orthoclase, diopside, actinolite, or hedenbergite, and locally the growth of these minerals has destroyed all remnants of the original sedimentary structures. However, the persistence of enough such features to render the formation identifiable is surprising, and there are only a few places where, if exposures are adequate, even the highly metamorphosed rocks cannot be satisfactorily referred to one or the other formation with considerable confidence. Thus an individual hand specimen of the hornfels in the Horquilla limestone may be indistinguishable from a similar-sized specimen of any one of several other formations, yet an outcrop 50 feet across may be rather definitely correlated. This correlation thus depends not on the minerals developed but on their spacial arrangement and the preservation of some traces of the original sedimentary disposition.

THICKNESS

As indicated in the section measured east of Horquilla Peak, the Horquilla limestone is about 1,000 feet thick. Because the top is cut off by a fault, the true thickness is more than 1,000 feet, as previously mentioned, but probably not more than about 1,200 feet, to judge from the maximum thickness implied by the mapping. Approximate measurements in the Dragoon Mountains indicate that it is also about 1,000 feet thick near Black Diamond Peak, although the beds there are standing nearly vertically and strike faulting cannot be excluded. Elsewhere in the area mapped, the formation cannot be accurately measured, for the widespread faulting has destroyed any continuous sections, and no definite marker beds have been recognized within it. Cooper's sections in the Dragoon quadrangle suggest, on their face, a northward thickening of the formation, but this may be due to my underestimation of the thickness in this area.

CONDITIONS OF DEPOSITION

The Horquilla limestone is evidently wholly of marine origin. There are only local evidences (current bedding) of particularly shallow water, and terrigenous material (shale, sandy shale) is very subordinate. Presumably the major part of the formation was laid down at considerable distance from shore in a moderate depth of water; and the fauna is rich and varied, probably implying a neritic habitat.

AGE AND CORRELATION

The fauna of the Horquilla limestone is discussed by Williams along with the faunas of the rest of the Naco group, following the description of the other formations. The correlations suggested by Williams are shown on plate 7.

EARP FORMATION

NAME

The Earp formation is named from Earp Hill (Gilluly and others, 1954), in sec. 5, T. 21 S., R. 23 E. on whose south slope the lower part is well exposed. (See pl. 13.) Unfortunately there is no continuous, unfaulted section of the entire formation in the area of this report. However, the presence of a very distinctive lithologic member in the formation permits piecing the section together. Accordingly, the type section is designated as extending from the saddle south of Earp Hill up to a conspicuous mottled, pink and gray limestone indicated in the section following; to avoid the faulting at this locality, the section was completed by the excellent exposure above this mottled bed about half a mile to the east on the same slope. Confidence in the identity of the mottled bed in these localities is strengthened by its persistence and characteristic appearance over wide areas in the Tombstone Hills. It is present at the foot of Colina ridge, northeast of the Prompter mine, and all along the foot of the ridge, northeast of Epitaph Gulch, as well as on the south side of Government Butte, to the south. There is only a short gap between the two sections that are here synthesized as the Earp formation. An apparently complete section is exposed about 3 miles north of the area of this report, on the northeastern spur of the Dragoon Mountains near the Golden Rule mine.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Earp formation crops out on the south slope of Earp Hill, as just mentioned; the west base of Colina Ridge; the southwest foot of the ridge bounding Epitaph Gulch on the northeast; and north of the Prompter fault in the Tombstone mining district. It is also found in the south, east and north sides of Government Butte and in the low hills 2 miles northeast of Earp Hill. In the hills near Gleeson the Earp crops out just west of the Courtland–Gleeson highway half a mile north of its junction with the Gleeson–Webb road. The formation has not been recognized in the Courtland district, though the overlying Colina limestone is present; but the intimate slicing of this district by thrust faults and the evident susceptibility of the Earp formation to serve as a gliding horizon probably account for this. It is also found on the west slope of the Dragoon Mountains south of Black Diamond Peak and in the main ridge north of Mount Glen.

Most of the areas underlain by the Earp formation are low. There are several fairly resistant ledges of limestone and dolomite in the formation, especially in its upper part; but the shales of the lower part of the formation are weak, and their erosion undermines the higher ledges. The characteristic outcrop of the formation is thus a gentle though interrupted slope at the base, steepening upward to a fairly persistent ledge beneath the relatively more resistant Colina limestone overlying it.

STRATIGRAPHY

The base of the Earp formation is only locally exposed, owing to its intrinsic weakness to the forces of erosion; to its position between more massive and competent beds, which has led to its shearing during the deformation of the rocks; and to its apparently fortuitous position at several localities along normal faults, where it is either much dragged or largely concealed by talus.

The one really good exposure of this part of the formation within the map area is on the lower slopes of Earp Hill, due south of its crest. Here, there appears to be no erosional or other discordance with the underlying Horquilla limestone. As given in detail in the following section, the base of the Earp is arbitrarily taken where the thin shaly limestones and reddish shales become dominant over the more massive limestones characteristic of the Horquilla. Much shale, a little sandstone, and a few beds of limestone and shale conglomerate occur somewhat higher in the section. This clastic zone gives way upward to more massive limestone with a few very conspicuous beds of dolomite that weather brilliant orange or reddish. These beds, though only a foot to 5 or 6 feet thick and interbedded with limestone that differs little from that of the overlying Colina, form a characteristic assemblage and constitute the best clue to the presence of the formation. They are commonly crossbedded and somewhat cherty. A characteristic specimen is illustrated in plate 1*B*. A few thin sandstones are found associated with these orange dolomites. The topmost of the dolomite beds is taken as the top of the Earp formation, though a local "stray" sandstone is found at higher levels in some places.

There is thus an arbitrary boundary with the overlying Colina limestone, though as a whole the Earp formation embraces the part of the Naco group that contains most of the clastic deposits.

The following is the type section of the Earp formation.

Section of Earp formation, on south side of Earp Hill (pl. 7, left hand section of this formation)

[Top part measured about half a mile east-southeast of the crest]

	Feet
Colina limestone:	
Limestone, almost black, weathers dark gray, in beds 2 to 4 feet thick.	
Earp formation:	
1. Dolomite, sandy, thinly laminated, varvelike, pink, weathers conspicuous orange tan, dense; sporadic nodules of coarse calcite up to 2 inches across, but averages one-half inch	5½
2. Limestone, very dark-gray, blue gray on weathered surface; forms ledge	11
3. Limestone, shaly, red, poorly exposed; forms slope	10½
4. Limestone, dark-gray, forms a low ledge	2½
5. Limestone, shaly (or limy shale), red, poorly exposed; forms slope	5½
6. Limestone, dark-gray, dense, beds about 2 feet thick; forms very prominent ledge	23
7. Sandstone, soft, shaly, weathers red brown, slope-former, a few thin limestone ledges	17
8. Sandstone, brown, well-cemented, caps ledge	⅓
9. Dolomite, like member 1 except no calcite nodules occur	1⅔
10. Limestone, blue-gray, dense, aphanitic, beds from 2 to 10 inches thick	4½
11. Concealed, probably limestone	2
12. Dolomite, slightly sandy, pink, weathers orange tan, varvelike laminations, some crossbedding, thin intraformational breccia at top	3
13. Concealed	1
14. Dolomite, like member 1	2½
15. Concealed, probably shale or thin-bedded limestone	4½
16. Dolomite, like member 1	3
17. Limestone and dolomite at base, thin-bedded (less than 6 inches), alternating; passes upward into maroon shale which constitutes most of the member	18
18. Limestone, microcrystalline, pink to dove, weathers very pale blue gray; average beds about 3 feet; 2 or 3 partings of orange-weathering dolomite an inch or two thick; considerable small chert nodules; top 2 feet contains pink shaly material anastomosing through the rock; fossil coll. USGS 8967	24
19. Dolomite, weathers orange; and pink limestone; forms secondary ledge	8
20. Limestone, massive, mottled with pink and white; little chert, no dolomite; this "marker" bed recognized in Government Butte, Colina Ridge, northeast of Epitaph Gulch, near the Prompter mine and elsewhere	22½
Section shifted to a point directly south of summit of Earp Hill—about 2,000 feet west of the line where the above section was measured.	
Section of lower part of Earp formation:	
21. Limestone, same as member 20; thrust fault cuts the section just above; 20 feet.	
22. Limestone and shale, poorly exposed; forms a slope with a 2-foot ledge of shaly limestone that weathers very dark brown near bottom of member; fossil coll. USGS 8970	23
23. Limestone, pink, mottled with orange-weathering dolomite; very cherty, large irregular blotches of brown-weathering chert especially prominent in dolomitic parts; forms massive ledge	11
24. Limestone, shaly, blue-gray, not well exposed	8
25. Limestone, blue-gray, ranges irregularly along and across the strike to pink and dove dolomite; much nodular chert that weathers conspicuous orange, especially prominent toward the top where it commonly forms a nearly solid ledge 6 inches thick; a massive ledge	4½
26. Concealed, probably soft limestone	9½
27. Limestone, weathers light gray, somewhat mottled by dolomite that weathers yellowish brown; contains much chert, weathers orange to red, in nodules and lenses up to 2 feet long by 2 inches thick	3½
28. Limestone, aphanitic, weathers light gray; silicified crinoid stems; average bed about 3 feet	9½
29. Concealed, probably mostly red shale and shaly limestone	37
30. Limestone, coarsely crystalline, pinkish gray; weathers dark yellowish brownish gray; highly fossiliferous, many gastropods; fossil coll. USGS 8969 and 8968	2
31. Shale, red, and blue-gray limestone, alternating, mostly nodular, shaly, and in beds up to 1 foot thick; not well exposed; forms slope	47
32. Sandstone, concretionary, maroon; weathers dark brown; partly crossbedded, partly evenbedded; grades downward into member 33; forms ledge	12
33. Sandstone, shaly, thin; sandy shale; blue-gray shaly limestone; all interbedded; much of limestone nodular and concretionary, some nodules appear abraded and may have undergone some transportation; member as a whole, soft, red brown to maroon; forms slope	42
34. Limestone, dense, dove-colored, somewhat shaly; nodular in lower part; massive; less shaly above; carries many brachiopods; forms a ledge; fossil coll. USGS 8508	5

Section of lower part of Earp formation—Continued	Feet
35. Sandstone, soft-gray to reddish-brown, crossbedded, very limy and shaly, thin-bedded; forms slope	75
36. Limestone conglomerate, carries angular to subrounded fragments, up to 2 inches across, average about one-fourth inch, of brown shale and gray limestone in matrix of gray limestone; soft at base, more resistant upward. (See pl. 2*C*.)	18
37. Limestone, dark gray on weathered surface; highly foraminiferal; forms ledge; fossil coll. USGS 8509	2
38. Limestone, red, locally weathers orange; silty, current-bedded; forms saddle. (See pl 2*A*.)	7
39. Limestone, dove-colored, weathers medium gray, stylolitic, carries many foraminifers	7
40. Shale, red, poorly exposed orange-weathering ledge of dolomite near base, more limestone interbeds upward	51
41. Limestone, dark-gray, weathers medium gray, crystalline; forms low ledge	2
42. Concealed, probably shaly limestone or limy shale	18
43. Limestone, dove-colored, weathers medium gray, dense, massive	4
44. Concealed, probably shaly limestone	3
45. Sandstone, limy, locally silicified, fine-grained, (average one-fourth mm), weathers conspicuous red brown	3½
46. Concealed, probably thin limestone or shale	3½
47. Limestone, gray, pink along joints, massive, aphanitic	4½
48. Concealed, probably thin-bedded limestone	3½
49. Limestone, dark-pinkish-gray, weathers medium gray	1½
50. Limestone, soft, thin-bedded, pinkish, 2-foot bed of orange-weathering dolomite near the middle	7
Total Earp formation	595

Horquilla limestone:

Limestone, dense, microcrystalline, gray, pink along joints, generally thick bedded (top bed is 4 feet thick).

The nearly ubiquitous bedding shears in the Earp formation prevent other detailed measurements of the formation within the map area. Allowing for estimated fault displacement, the section at the west base of Colina Hill is about 615 feet thick. Another, west of Dragoon Camp, is near the same thickness. What appears to be an essentially complete section measured 577 feet thick on the mountain spur west of the Golden Rule mine, about 3 miles north of the quadrangle.

Section of Earp formation, on spur southwest of the Golden Rule mine, Dragoon Mountains (shown on pl. 7 as the middle section of this formation)

Colina limestone:

Limestone, dark-gray, somewhat sheared near base and there mottled with pink, otherwise dull gray throughout.

Conformable contact.

Earp formation:	Feet
1. Limestone, blue-gray, mottled with pink	2
2. Shale	3
3. Sandstone, brown, dolomitic	7
4. Shale	10
5. Limestone, mottled, somber brown and gray, in beds 1–4 feet thick, average about 2 feet	36
6. Sandstone, yellow-buff, weathers reddish brown, fine-grained, limy	8
7. Limestone, mottled, pink and blue, weathers reddish gray, beds average 1 to 2 feet thick, but range up to 6 feet, interbedded with subordinate blue-gray and pinkish shale	51
8. Dolomite, pinkish-gray, weathers conspicuous orange tan, massive, dense	2
9. Shale, purplish	6
10. Limestone, shale, sandstone, and dolomite, interbedded; limestone, blue-gray, in beds ½–2 feet thick; dolomite, pinkish-gray, weathers orange tan, in beds of about the same thickness; a few thin brown-weathering sandstones and considerable purplish shale make up more than half the interval	55
11. Shale, purple	12
12. Limestone, dense, dark blue gray on fresh fracture, weathers very dark gray, in beds 2–4 feet thick	10
13. Sandstone, very light-gray to almost white, weathers light brown; crossbedded, ripple-marked; in beds up to 4 feet thick	19
14. Limestone, fine-grained, pink, weathers purplish gray and brown gray, in beds 1–3 feet thick; interbedded with thin shale partings	25
15. Sandstone, dolomitic, gray, weathers dark brown, current-bedded, ripple-marked	8
16. Shale and sandy dolomite; interbedded, shale, purplish, makes up about three-quarters of the interval; dolomite layers 1–2 feet thick, weathers orange tan	53
17. Breccia, sandstone, and dolomite fragments, some irregular chert nodules	1
18. Sandstone, dolomitic, ranges to sandy limestone; current-bedded	4
19. Limestone and shale in alternating beds, a few discontinuous thin beds of dolomite that weather orange tan; limestone mottled pink and white, beds range from 1 to 3 feet in thickness, contains irregular chert masses that weather brown; interbedded shales, purple and green	60
20. Limestone, conspicuously mottled pink and white; forms prominent ledge	7
21. Shale, bluish	23
22. Limestone, dolomitic, weathers orange in the top few inches, gray below, ledge-forming	3
23. Shale, greenish-gray	1
24. Limestone, coarsely crystalline marble in part, mottled pink and white; forms prominent ledge	15
25. Shale, green, gray limestone, and pink- and white-mottled limestone; limestone ledges 2–4 feet thick; shale somewhat thicker	107
26. Limestone, pinkish-gray, weathers mottled brown; forms strong ledge	5
27. Shale, greenish-gray	7
28. Limestone, bluish-gray, weathers red brown	3

Earp formation—Continued	*Feet*
29. Shale, green, micaceous; grades into member 30	4
30. Sandstone, platy, shaly, current-bedded, gray, weathers brown	5
31. Limestone, pinkish-gray, weathers mottled brown; forms ledge	7
32. Shale, platy, limy	8
33. Limestone, mottled with dolomite, pink, weathers yellow	2
34. Limestone, shaly, reddish, thin-bedded	8
Total thickness of Earp formation	577

Conformable contact.

Horquilla limestone:

Limestone, fine-grained, pale-blue-gray, weathers almost white except for one bed near top that weathers very dark gray, in 2-foot beds.

THICKNESS VARIATIONS

Within the map area there is thus practically no evidence of lateral thickening of the formation. But in the Gunnison Hills, Dragoon quadrangle, north of the area shown in plate 5, and only 5½ miles northwest of the Golden Rule locality, Cooper has measured 1,126 feet of beds assigned to the Earp (Gilluly and others, 1954). The formation thus appears to be thickening abruptly northward.

CONDITIONS OF DEPOSITION

The Earp formation is apparently wholly marine. The shales closely resemble those of the Horquilla except in their much greater thickness. Though the lower limestones are like those of gray with a pinkish cast in the Horquilla, the upper limestones are dense and nearly black like the limestones of the Colina. The suggestion is that the interbedded conglomerates in the lower third of the formation may record a time break, but all the pebbles these contain can be matched in nearby underlying beds. Thus the conglomerates seem wholly intraformational, perhaps formed during big storms. However, in the section measured by Cooper in the Gunnison Hills, the conglomerate about two-thirds of the way above the base contains large cobbles of sandstone not like any subjacent rocks. Further, these conglomerates separate members that are lithologically and faunally distinct. Hence, despite the greater thickness of the formation in the northern area, these foreign boulders suggest uplift of land somewhere to the northwest of this area. It is possible, therefore, that although the conglomerates in the area of plate 5 are wholly intraformational, they may record a considerable interruption in sedimentation.

STRUCTURAL AND METAMORPHIC FEATURES

The intercalated shales of the Earp formation evidently constitute gliding zones even in areas of rather simple and open folds. In the zones of intense deformation exposed in the south face of Government Butte and along the entire Dragoon Mountains, the formation has been greatly thinned or repeated by movements along these beds or cutting them at low angles. The shearing out of the shales and shaly limestones has had the effect of giving the formation an apparently higher proportion of sandy beds in many places. However, except in areas of thermal metamorphism, the associated orange-weathering beds of dolomite retain their characteristic colors and constitute a most useful guide to the distribution of the formation. The foraminiferal beds, too, even where greatly sheared, preserve recognizable fossils that are considerably larger than the ones found in the Horquilla and confirm the determination.

In areas of thermal metamorphism the Earp is highly altered. Like the Martin, it is almost ideally constituted for the production of contact silicates and is thus represented by hornfels for long distances from many intrusive contacts in the northern Dragoon Mountains. These rocks preserve clear traces of the original stratification and even of crossbedding; and the intercalations of bands rich in feldspar and epidote, both with those rich in quartz and diopside and with others containing abundant tremolite or diopside, give clues to the original characteristic interbedding of shale, limy sandstone, and dolomite and limestone. Though the formation thus resembles similarly metamorphosed parts of the Martin and the Epitaph dolomite, its stratigraphic position and the crossbedding in many of the dominantly limy beds generally suffice to identify it. In some localities, however, the formation has probably been included in the rocks mapped as undifferentiated Paleozoic.

COLINA LIMESTONE

NAME

The Colina limestone is named from its excellent exposures on the west side of Colina Ridge, a mile south of Horquilla Peak (Gilluly and others, 1954) (pl. 12).

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Colina limestone is one of the most widespread of the Paleozoic formations. It makes up most of the Tombstone Hills south of the Horquilla Peak fault as well as Earp Hill and the nearby hills to the northeast. This limestone also constitutes most of Government Butte and is present at the extreme south of the map area on the west foot of the Mule Mountains. Only small slices of the formation are found in the hills near Gleeson, but larger blocks are present in the Courtland district. In the shingle-fault area extending east and west of Barrett Camp and into the south wall of South

Pass, there are several narrow blocks of the Colina limestone. This formation does not crop out in the south end of the main ridge of the Dragoon Mountains, but it is present near the crest west of Dragoon Camp and in smaller bodies north of Mount Glen, near Middlemarch Canyon, and southeast of the Fourr Ranch.

Where the Colina limestone is thick bedded, it is resistant and forms cliffs only slightly less precipitous than those of the Escabrosa. The thinner beds, although practically free from shale, tend to produce shelves in the topography, and there are enough of them to reduce the boldness of outcrops of the formation to one intermediate between that characteristic of the Escabrosa and that of the Horquilla.

STRATIGRAPHY

As mentioned in the description of the Earp formation, the lower boundary of the Colina limestone is taken arbitrarily at the highest of the dolomite beds that weather to an orange-red surface. This places nearly all of the clastic rocks—the sandstone and shale beds—in the Earp formation, but in some places there is a stray sandstone bed considerably higher in the section; that is, in the lower part of the Colina limestone.

The most characteristic lithologic feature of the Colina limestone is the dominance of dense limestone that appears very dark gray to almost black on fresh fracture. The field name adopted for the formation was "the black limestone," which emphasizes its most conspicuous distinction. Similar beds are locally found in other of the formations of Carboniferous age. These, however, are rarely more than a few feet thick and are associated with limestones of light gray or pinkish cast on fresh fracture. Such lighter or pinkish beds have not been seen in the Colina limestone; it seems safe to conclude that in this area any continuous section as much as 20 feet thick that consists of dense limestone whose fresh fracture is dark gray to black is part of the Colina limestone. This hypothesis has been tested by fossil collections in many localities, and no inconsistencies have been discovered. It should be pointed out that, although the Colina limestone generally weathers to dark gray, it locally weathers to light gray or almost white despite the very dark color on fresh fracture.

A further feature valuable in discriminating the Colina limestone from the other limestone formations is the great abundance of gastropods in it. Several of these gastropods are very striking, notably a very large obtuse-angled *Omphalotrochus*. This fossil has not been noted in other formations of the area. It attains a height of 5 or 6 inches, and specimens 3 or 4 inches high are common. Brachiopods are present but far less commonly than the gastropods—a relation that is reversed in the Horquilla limestone. Chert is not abundant in the Colina limestone but where present commonly forms irregular nodules rather than lenses or beds as it does in the Horquilla.

The upper limit of the Colina limestone, like the lower, has been chosen arbitrarily as no disconformity has been recognized. The transition to the overlying Epitaph dolomite takes place through a zone of variable thickness in which the limestone is mottled with dolomite in proportions that increase upward, finally passing into massive dolomite. In places this transitional zone is as much as 30 feet thick, but more commonly it is less than 4 feet between the essentially nondolomitic limestone of the Colina and the essentially noncalcitic dolomite of the basal Epitaph. As the dolomite of this zone is apparently secondary, the transition beds are here included in the Colina limestone, though the zone is so thin as to be immaterial in mapping on the scale of plate 5.

The following section of the Colina limestone was measured on the west slope of Colina Ridge in the Tombstone Hills as the type section of the formation.

Section of the Colina limestone, on Colina Ridge, 4,000 feet south of Horquilla Peak (pl. 7, left hand section)

	Feet
Epitaph dolomite:	
Dolomite, finely crystalline, black, weathers dark gray to yellow gray and buff, in beds 6–12 inches thick.	
Colina limestone:	
1. Limestone grades upward into dolomite; toward base, dense black limestone weathers blue gray, mottled with brown-weathering dolomite; dolomite increases upward; top of ledge all dolomite	8
2. Limestone, black, weathers medium gray, dense; beds range from 6 to 12 inches in thickness at base, become thicker upward; some 8-foot beds near top	173
Sill of granitic porphyry	12
3. Limestone, black, like member 2 but in beds 6–12 inches thick	13
4. Limestone, like member 2 but in beds 4–20 feet thick; many large *Omphalotrochus* and bellerophontid gastropods; fossil coll. USGS 8965	99
5. Limestone, black (a few beds at the top with minor dolomite that weathers yellowish), beds mostly less than 12 inches thick but range up to as much as 4 feet	74
6. Limestone, black, weathers light to medium gray, beds 4–12 feet thick; forms ledge; many gastropods; fossil coll. USGS 8964	44
7. Limestone, like member 6 but in beds 2–4 feet thick, forms slope; contains a little chert in nodules about 3 centimeters across; fossil coll. USGS 8963	37
8. Limestone, like member 6, beds up to 10 feet thick; forms a ledge	51

Colina limestone—Continued	*Feet*
9. Limestone, black, in beds 1–6 inches thick; buff sandstone 8 inches thick about 6 feet above the base; about 8 feet of shaly limestone forms slight saddle at the top	30
10. Limestone, very dark-gray, weathers light gray, aphanitic, in beds 2–4 feet thick that form a ledge	45
11. Sandstone, limy, weathers brown	1
12. Limestone, black, weathers dark gray, dense, in beds 6–12 inches thick; shows a few sandy streaks that emphasize bedding; few thin shale and dolomitic layers in lower 40 feet; fossil coll. USGS 8962	58
Total Colina limestone	633
Earp formation:	
Sandstone, limy, pink, weathers dark brown; rests on orange-weathering dolomite	4½

Owing to structural complexities, no other sections of the Colina were considered suitable for measurement. The mapping, however, is consistent with a practically uniform thickness throughout the area of plate 5, except where the formation had been eroded prior to deposition of the Comanche rocks.

The Colina limestone in areas of intense differential movement is generally much lighter colored on fresh fracture than in its less-deformed facies. The fine grain permits distinction from the Escabrosa, which is commonly coarse grained even where strongly sheared; but in absence of its characteristic color, distinction from the Horquilla limestone becomes difficult, especially if fossils are not recognizable. The Foraminifera of the Colina are generally considerably larger than those of the Horquilla, and this distinction is surprisingly recognizable even where the rocks have been greatly stretched. Where the movement has been extreme, however, distinguishing the Colina from either the Escabrosa or Horquilla becomes impossible, and such areas have been mapped as undifferentiated Paleozoic.

The scarcity of detrital or magnesian minerals renders the Colina less susceptible to metamorphism than either the Earp or the Epitaph. However, differences from the Horquilla in this respect are insignificant, and it is not certain that the formation has been consistently recognized in the contact zones about the Stronghold granite, where using its stratigraphic relations to rocks more readily recognized has been necessary. Thus the structural interpretations of these areas presented in this report may possibly be simpler than the facts would warrant if the formations were all definitely recognizable.

EPITAPH DOLOMITE

NAME

The Epitaph dolomite is so named (Gilluly and others, 1954) because of its good exposures on the west side of Epitaph Gulch—the eastern slope of Colina Ridge. (See pl. 13.)

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Epitaph dolomite is not so broadly exposed as the other formations of the Naco group. It crops out in the low hills northwest of Boquillas, in the Tombstone district: at the north end of the Tombstone Hills on Comstock Hill just northwest of Tombstone, in the faulted area southwest of Ajax Hill, near the Luck Sure and Lucky Cuss mines, at several places in the area from Epitaph Gulch to Earp Hill, and in the hills to the northeast of Earp Hill. Two small outcrops occur in the valley north of Government Butte, and in the Dragoon Mountains small bodies of the formation are present in the thrust fault zone near Barrett's Camp and southeast of Gleeson. North of Mount Glen and near Dragoon Peak, there are other bodies; and it is present outside the map area near the Golden Rule mine, at the northeast edge of the Dragoon Mountains.

The lower part of the Epitaph dolomite is relatively resistant and commonly forms topographic eminences. The upper part, however, in which considerable shale and thin-bedded limestone occur, is much less resistant to erosion. It commonly forms the foot of dip slopes.

STRATIGRAPHY

The base of the Epitaph dolomite is arbitrarily set at the base of the first massive dolomite above the zone of partly dolomitized limestone at the top of the Colina limestone. Although the partial dolomitization of the uppermost beds of the Colina limestone is obviously an epigenetic feature, there is no apparent reason to attribute the dolomite of the Epitaph to subsequent metamorphism of an original limestone. However, even if the dolomite is secondary, it is nevertheless a map unit of stratigraphic value, for the rocks are everywhere markedly different from the underlying Colina limestone. Wherever the upper part of the formation is preserved, it is apparent that the limestone-shale sequence characteristic of this part rests on about equivalent thicknesses of dolomite. Accordingly, the dolomite is regarded as probably primary or diagenetic and not as metamorphic in origin.

Approximately 200 feet of dolomite forms the lowest member of the formation. This dolomite differs notably from all the others in the stratigraphic section. It ranges from medium to light gray and weathers from light to very dark gray. One of the most characteristic features of these rocks is the presence of knots of silica—the larger ones with a central cavity—that weather out on the surface. Some of these give suggestions of being silicified fossils, but the minute euhedral quartz crystals that commonly coat them obscure the original form of the nuclei. If they do represent fossils they are no longer identifiable. Along with these nodules are much finer granules of silica strewn parallel to the bedding. These are also largely euhedral quartz crystals but may represent secondary enlargement of detrital grains. They commonly weather brown or tan. All these dolomite beds weather with a rough "elephant-hide" surface. Representative specimens are shown in plate 3*A*, *B*.

Toward the top of this part of the formation, partings of red shale occur in the dolomite. The overlying beds are generally poorly exposed sandy limestone or limy sandstone with a higher proportion of maroon shale and much less dolomite. Some of these beds are intraformational breccias, and crossbedding, ripple marks, and other evidences of a shallow-water environment are conspicuous.

The uppermost part of the formation is an assemblage of dolomite, limestone, red shale, and thin sandy layers. A few fossils are present in this member—among them some indeterminate bellerophontid specimens about the size of a tennis ball.

The upper limit of the formation is a very marked unconformity above which is found the Glance conglomerate or other rocks of Comanche or later age.

The following section illustrates the lithology of the formation at the type locality.

Section of Epitaph dolomite measured on the dip slope of Colina Ridge, west of Epitaph Gulch, 1 mile south of Horquilla Peak (pl. 7, left hand section)

	Feet
Glance conglomerate:	
Conglomerate, containing boulders and pebbles of dolomite, limestone, granite, rhyolite, and quartzite, about 100 feet exposed; unconformity—slight angular discordance locally (about 15°) but erosional surface of relief exceeding 20 feet in 100 yards.	
Epitaph dolomite:	
1. Limestone, blue, weathers gray, fine-grained, some beds up to 2 feet thick but chiefly thinner than 4 inches; fossil coll. USGS 8515	103
2. Limestone, gray, massive	9
3. Limestone, blue-gray with greenish cast, interbedded with maroon-weathering dolomite in beds ordinarily less than 2 inches thick but ranging up to 2 feet; dolomite diminishes upward, giving way to limestone	17
4. Dolomite and shaly limestone, with much sand distributed throughout	84
5. Dolomite, forms ledges; limestone, shaly; and mudstone, limy, forms saddles; all interbedded; some dolomite and mudstone sandy; shaly parts maroon; tops of many ledges sedimentary breccias; member about one-third dolomite and two-thirds other rocks	75½
Epitaph dolomite—Continued	
6. Dolomite, massive, finely crystalline, reddish-gray, weathers somber brownish gray; forms strong ledge and dip slope on prominent sharp spur of ridge	13½
7. Concealed, probably maroon shale	6
8. Dolomite, coarsely crystalline, pink, weathers yellow gray; forms massive ledge	25
9. Shale and dolomite, alternating, poorly exposed	10
10. Dolomite, massive, slightly sandy, red-brown, weathers buff	8
11. Breccia, dolomitic, sedimentary	2
12. Concealed, probably shale and thin dolomite beds	26
13. Dolomite, red-brown, weathers light cream to buff	6
14. Mudstone, red, contains dolomite fragments, poorly exposed	33
15. Dolomite, cream-colored, cracks in upper surface filled during sedimentation by muddy breccia-like member 14	5
16. Concealed	8
17. Limestone, sandy, bright-red, weathers brown and buff; massive	4
18. Limestone, soft sandy, red, or limy sandstone, poorly exposed; some thin beds of dolomite and maroon shale; forms prominent saddle on ridge; fossil coll. USGS 8966	74
19. Dolomite, buff-weathering, in beds 4–6 inches thick, thin shaly partings	58
20. Sandstone, yellow-weathering, poorly exposed	11
21. Dolomite, finely crystalline, black to dark-gray, weathers dark gray, yellow gray, pale gray, and buff; local thin streaks of brown-weathering quartz grains; beds from 6 inches to 2 feet thick, mostly less than 1 foot; many siliceous geodes and quartzose knots from ¼ inch to 2 inches in diameter occur and weather out on the surface	205
Total Epitaph dolomite	783
Colina limestone:	
Limestone, mottled with brown-weathering dolomite that becomes more abundant upward; transition to massive dolomite here occurs in about 4 feet, stratigraphically.	

The lower part of the Epitaph dolomite is the only thick dolomite in the stratigraphic column of the area. Accordingly, it is readily recognized even in complexly faulted areas where the stratigraphic relations cannot be used as guides to correlation. In places the upper part, consisting of interbedded dolomite, sandstone, shale, and limestone, is sufficiently like the Earp formation to be distinguished only with difficulty.

As a whole, the formation is more susceptible to contact metamorphism than most of the other rocks of the region. On Comstock Hill, in the Tombstone district, and north of Mount Glen, in the Dragoon Mountains, the dolomitic part has been dedolomitized, with the formation of abundant diopside, grossularite, tremolite and labradorite, and locally idocrase, epidote, and other silicates. The association of these thick beds, obviously derived from dolomite, with hornfels derived from the overlying shale, renders the correlation of the rocks in these areas with the unaltered Epitaph extremely probable, and the doubt that must always exist in such correlations does not appear to require further qualification.

THICKNESS

The pre-Comanche unconformity, although locally marked by slight angular discordance, is elsewhere a record of major deformation. Rocks of Paleozoic and earlier age were highly folded, locally invaded by large igneous masses, and then deeply eroded. As a result, the Epitaph dolomite, the topmost Paleozoic formation in this area, was eroded away in larger measure than any of the lower formations. In the Tombstone Hills this erosion cut down to lower horizons to the north and east from the type locality, so that only a few score feet of the dolomite intervene between the Colina limestone and the Glance conglomerate in the area northeast of Earp Hill. Even on the east side of Epitaph Gulch the formation is several hundred feet thinner—owing to erosion of its top—than it is at the type locality. The absence of all post-Horquilla rocks of Paleozoic age near the Fourr Ranch and the presence of several hundred feet of Epitaph dolomite near the Golden Rule mine, about 6 miles to the northeast, show the thinning to be local rather than regional.

Doubtlessly the sporadic and sparse distribution of the formation in the Dragoon Mountains is in large part due to the pre-Cretaceous erosion as well as to the post-Comanche thrust faults.

CONDITION OF DEPOSITION

The lower third of the Epitaph dolomite contains little terrigenous sediment. Whether the dolomitization resulted from slow deposition in shallow waters, as has been postulated for certain other dolomites (Nolan, 1935, p. 22–23) and is suggested by features indicative of shallow water in higher parts of the formation, cannot be decided without detailed investigation. The sedimentary breccias, crossbedding, ripple marks, and high proportion of sand and shale all suggest strongly that the upper part of the formation was laid in shallow water. The marine fauna sparsely represented in the upper part of the Epitaph dolomite shows it to be marine, as is the lower part almost certainly.

The faunules collected from the Naco group were studied both in field and laboratory by James Steele Williams, who has contributed the following discussion.

AGE AND CORRELATION OF THE NACO GROUP

By JAMES STEELE WILLIAMS [4]

HORQUILLA FAUNA

The Horquilla fauna is a distinctive one that is here referred to a combined Lampasas (*)[5] and Des Moines age. No beds of Morrow (earliest Pennsylvanian) age were recognized, and rocks of this age are probably absent as collections containing Lampasas (*) and Des Moines types of fossils (*Mesolobus*) directly overlie Mississippian rocks in several places. Another alternative would be that the faunal facies of Morrow age is here indistinguishable from the Lampasas (*). A few species typically of Morrow age have been tentatively identified, but for the most part these are in collections having other fossils that are typically of Lampasas (*) and Des Moines age. The identifications, being tentative, may be in error; or the ranges of the Morrow fossils may be extended.

No attempt is made to separate a Lampasas (*) faunal zone from a Des Moines faunal zone, because the faunal criteria so far listed for such a separation have not been tested adequately on a wide geographic basis, particularly in the West for the larger fossils, if indeed for any other fossils. Mr. Henbest has referred one fusulinid collection (F233) to an upper Atoka, Lampasas (*), or early Des Moines age and others definitely to a Des Moines age, but for the purposes of this paper a combined Lampasas (*) and Des Moines age is satisfactory.

Perhaps the most abundant fossils in the Horquilla collections are brachiopods, but many fusulinids also occur as well as significant coral and bryozoan elements in the fauna and some pelecypods, gastropods, and trilobites. The pelecypods and gastropods are neither common nor significant as age determinants. The trilobites are few in number and also happen to lack important significance. Crinoid columnals are common, and there is an occasional echinoid spine.

Several representative faunules will show the general composition of the Horquilla fauna.

Collection 8385, from beds about 50 feet above the saddle taken as the base of the Horquilla, on Horquilla Peak, the type section (member 18, p. 37.)

Fusulinids (misplaced or lost)
Spirifer rockymontanus var. *opimus* Hall

[4] Credit for identifications of the following invertebrate fossils assembled in the faunal lists published in this discussion of the Naco should be given as follows: Fusulinids, L. G. Henbest; corals and bryozoa, Helen Duncan; gastropods, J. Brookes Knight; cephalopods, A. K. Miller; and trilobites, J. Marvin Weller. The writer has identified the species of other classes and except where others are directly quoted has supplied the age designations and discussions. Most of the discussions were prepared and the identifications of the fossils were made in 1946 and 1947 and reflect the terminology in use at that time.

[5] The term "Lampasas" has not been officially adopted by the United States Geological Survey. All such terms are indicted by (*).

Composita sp. indet.
Mesolobus striatus Weller and McGehee
sp. indet.
Marginifera? sp. undet.
Rhynchopora magnicosta? Mather
Punctospirifer kentuckyensis (Shumard)

Other collections regarded as typical of the Horquilla are 8480, 8932, 8935, 8946, and 8948. The fossils in these collections are listed below.

Collection 8480, from creekbed of main south tributary of Tombstone Canyon, Mule Mountains, 1,000 feet south of highway at 4,750 feet altitude

Empodesma? sp.
Zaphrentoid coral, probable new genus
Caninia sp. A
Spirifer rockymontanus Marcou, n. var. A
Phricodothyris perplexa (McChesney)
Crurithyris? planoconvexa (Shumard)
Composita sp. indet.
Marginifera? sp. undet.
Rhipidomella? carbonaria (Swallow)
Hustedia mormoni (Marcou)
Dielasma? sp.

Collection 8932, from point about 200 feet above base of Horquilla type section (member 17, p. 37)

Caninia sp. A
Caninia? sp. E
Crinoid stems
Fistuliporoid bryozoan, incrusting type 1
Chainodictyon sp.
Fenestella sp. 4
Rhomboporoid bryozoan, genus indet.
Prismopora sp.
Spirifer rockymontanus Marcou
Neospirifer dunbari King
sp. undet.
Phricodothyris perplexa (McChesney)
Derbyia? cf. *D. crassa* (Meek and Hayden)
Chonetes granulifer Owen
Mesolobus striatus Weller and McGehee
sp. indet.
Dictyoclostus coloradoensis (Girty), n. var. A
Echinoconchus semipunctatus knighti? Dunbar and Condra
Pustula? sp. undet.
Linoproductus prattenianus (Norwood and Pratten)
Schizophoria? sp. undet.
Punctospirifer kentuckyensis (Shumard)

Collection 8935, from west side of foothill ridge west of Colina Ridge, sec. 26, T. 20 S., R. 22 E.

Lophophyllidium sp. B
Crinoid stems
Fenestella sp. indet.
Prismopora sp. indet.
Spirifer rockymontanus Marcou, n. var. A
Neospirifer sp. undet.
Composita subtilita (Hall)
Derbyia? cf. *D. crassa* (Meek and Hayden)
Mesolobus sp. indet.
Dictyoclostus? sp. undet.
Linoproductus sp. undet.
Hustedia mormoni? (Marcou)

Collection 8946, from breccia block in thrust area, SE¼ sec. 5, T. 20 S., R. 25 E.

Ammodiscus? sp.
Endothyra sp.
Millerella? sp.
Fusulinella? serotina Thompson
Wedekindellina euthysepta (Henbest)
(or *Fusulinella?*) *perforata* (Roth and Skinner)
Fusulina aff. *F. leei* Skinner
Tetrataxis sp.
Caninia sp. A
Multithecopora? sp. indet.
Spirifer rockymontanus Marcou, n. var. A
Neospirifer sp. undet.
Dictyoclostus coloradoensis (Girty), n. var. A?
Marginifera? sp. undet.
Linoproductus sp. undet.
"*Productus*" sp. undet.
Rhynchopora? sp. undet.
Punctospirifer kentuckyensis (Shumard)
Hustedia mormoni (Marcou)

Collection 8948, from thrust plate overlying Bolsa quartzite and Abrigo limestone in NE¼ sec. 5, T. 20 S., R. 25 E.

Caninia sp. D
sp. indet.
Michelinia? sp. indet.
Multithecopora? sp. B
Crinoid stems
Prismopora? sp. undet.
Mesolobus sp. indet.
Dictyoclostus coloradoensis (Girty), n. var. A
Dictyoclostus? sp. undet.

Collection 8533 contains some species, tentatively identified, that are more characteristic of younger beds, but these are associated with what is otherwise a typical Horquilla assemblage and the age of these beds is considered to be Lampasas (*) and Des Moines. The following forms were identified from this collection.

Collection 8533, from an altitude of 4,950 feet, on the north side of the Tombstone Hills in the SW¼ sec. 18, T. 20 S., R. 23 E.

Crinoid stem
Fenestella sp. 3
Polypora sp.
Penniretepora sp.
Rhomboporella sp. B
Prismopora sp.
Orbiculoidea capuliformis (McChesney)
Neospirifer dunbari King
Cleiothyridina orbicularis (McChesney)
Derbyia? cf. *D. crassa* (Meek and Hayden)
Derbyia? hooserensis elliptica Dunbar and Condra
Meekella striatocostata (Cox)
Mesolobus sp. indet.
Chonetina? cf. *C. flemingi* (Norwood and Pratten)
Dictyoclostus americanus Dunbar and Condra
Buxtonia? sp. undet.
Echinoconchus sp. undet.

Linoproductus prattenianus (Norwood and Pratten)
"Productus" n. sp. 1

Of the brachiopods in the above lists, *Mesolobus* and *Spirifer rockymontanus* Marcou are widely known as indicative of beds of pre-Kansas City–post-Morrow age.

Of the Horquilla corals Miss Duncan says—

Characteristic cup corals from rocks definitely of Lampasas (*) and Des Moines age in the area are the caninoids (*Caninia* sp. A, B, D, and E) and a few lophophyllids (*Lophophyllidium?* sp. B and C, and *Stereostylus?* sp. A). Specimens of zaphrentoid corals (*Empodesma?* and a form that is probably a new genus) occur in one collection (8480).

Syingoporoid corals occur with typical Lampasas (*) and Des Moines fossils in collections 8948 (*Multithecopora?* sp. B), 8946 (*M.* sp. indet.), and 8531 (*Syringopora* sp. 3?).

Collections that are referred to the Horquilla but that might be from the Earp contain, in addition to specimens of lophophyllids and *Caninia*, *Dibunophyllum* (coll. 8487, 1 specimen), *Syringopora* sp. 2 (coll. 8953), *Multithecopora?* sp. A and C, and another syringoporoid (*Pseudoromingeria?* sp. B?) at station 8944.

In collections recently studied from the nearby Dragoon quadrangle, these three types of syringoporoid corals (*Syringopora*, *Multithecopora?*, and *Pseudoromingeria?*) occur in collections from rocks assigned to the Earp on stratigraphic position or faunal evidence. Further collecting may show that they are more characteristic of the upper than of the lower Pennsylvanian in this area, but not enough is known of the ranges of these species to make any such statement at present.

Regarding the bryozoans, Miss Duncan says—

The Horquilla collections contain varied types of bryozoa though specimens of most species are not abundant. Assemblages of Lampasas (*)-Des Moines age contain a species of incrusting fistuliporoid, an indeterminate stenoporoid, one specimen of *Chainodictyon*, one or more species of *Fenestella*, a species of *Polypora*, *Penniretepora*, two species of *Rhomboporella*, other indeterminate rhomboporoids, as well as *Prismopora*, which occurs in four collections.

Several collections tentatively assigned to the Horquilla but that might be Earp contained the same types of incrusting fistuliporoids, *Fenestella*, *Polypora*, *Penniretepora*, and *Rhomboporella*. Additional genera identified in these collections are *Tabulipora* and the rhomboporoids *Ascopora* and *Rhabdomeson*.

Lists of fossils mentioned in all collections cited in the stratigraphic section of the Horquilla given on page 37, together with lists from collections from other stratigraphic sections, are given in the paper by Gilluly, Cooper, and Williams (1954). A study of collections examined in connection with the paper by these authors indicates that, whereas all the collections cited from the Horquilla in the stratigraphic section in the present report are of Des Moines or older age, some few other collections from the Pearce and Benson quadrangles cited in the Gilluly, Cooper and Williams report suggest the presence of beds of post-Des Moines age in the top of the Horquilla in these quadrangles. In the Dragoon quadrangle, adjoining to the north the area considered in this report, collections show that as much as the upper one-third of the formation is post-Des Moines (early late Pennsylvanian) in age.

EARP FAUNA

The collections from the Earp formation are not numerous or large; and many of them are not distinctive, especially those from the lower part of the formation. There is, of course, in them a complete absence of the typical Des Moines forms, such as *Mesolobus*, *Spirifer rockymontanus*, and the common Des Moines fusulinids and bryozoans that are present in most Horquilla collections, especially those from the middle and lower part. Brachiopods are still a dominant group; but in keeping with the general paucity of fossils, even they are relatively few in number. There are fusulinids in certain collections and a very few corals, bryozoans, and trilobites. One or two collections have echinoid spines.

The following characteristic species were collected from the Earp formation.

Collection 8528, from the gulch 2,000 feet north of the crest of hill 5501 in sec. 23, T. 21 S., R. 23 E., Pearce quadrangle, referred to the Earp

Neospirifer kansasensis (Swallow), n. var. A
Phricodothyris perplexa (McChesney)
perplexa (McChesney), n. var. A
Composita subtilita (Hall)
Derbyia? cf. *D. crassa* (Meek and Hayden)
Chonetes granulifer Owen
Pustula? sp. undet.
Linoproductus prattenianus (Norwood and Pratten)
Pelecypods, 3 species, undet.
Glabrocingulum? sp. indet.
Amphiscapha sp. indet.
Ditomopyge sp. undet.

Collection 8529 made at a point 1,500 feet due north of the crest of the 5501 hill in sec. 23, T. 21 S., R. 23 E.

Echinocrinus
Septopora sp. indet.
Composita sp. indet.
Derbyia ciscoensis Dunbar and Condra
Strophalosia (*Heteralosia?*) sp. indet.
Amphiscapha cf. *A. catilloides* (Conrad)

Collection 8938, from low ridge just west of common corner of secs. 26 and 34, T. 20 S., R. 22 E., west of Colina Ridge contains the following

Triticites secalicus (Say)
sp. (probably)
Caninia sp. A?
Pseudoromingeria? sp. B

The presence of the brachiopods *Derbyia ciscoensis* Dunbar and Condra, which is closely related to *D. multistriatus* (Meek and Hayden), and *Neospirifer kansasensis* (Swallow) and the absence of characteristic Des Moines brachiopods and other faunal elements of Des Moines age establishes the age of the Earp as late Pennsylvanian or Permian(?) (Wolfcamp, Big Blue). In the lower part it probably contains beds of late Pennsylvanian age and in the upper part, beds of Wolfcamp age. The upper Pennsylvanian brachiopod *Dictyoclostus americanus* Dunbar and Condra occurs in some collections assigned to the Earp, but either *D. americanus* or a closely related form occurs also in the Horquilla.

Triticites secalicus (Say) and *Triticites* sp. identified by Mr. Henbest in collection 8938 are said by him to be "definitely of upper Pennsylvanian age (unlikely as young as basal Permian) and more exactly appear to belong in or near the lower Virgil."

Another collection 3518, is probably from the Earp and composed wholly of fusulinids, from altitude 5,900 at point 1.2 miles N. 25° W. of Mount Glenn. Regarding it Mr. Henbest says—

I would like to withdraw my original determination of these metamorphosed specimens as *?Triticites obesus* (Beede). The uncertainty of my identification should have been expressed more strongly. It could not be proved that these are not a complex species of *Fusulina* such as occur in the upper Des Moines, though they do appear more like a new species of *Dunbarinella* (formerly included with *Triticites*) or possible *Triticites*. These seem most likely to indicate middle or upper Virgil age but might be upper Des Moines or basal Wolfcamp.

According to Duncan, "The only corals found with faunal assemblages of definite upper Pennsylvanian age are fragmentary caninoids that appear similar to *Caninia* sp. A, which is characteristic of the Horquilla-and the syringoporoid *Pseudoromingeria?* sp. B."

Regarding the bryozoans Miss Duncan says—

Septopora was identified in one collection (8529) definitely assigned to the Earp. This genus seems to be characteristic of the upper Pennsylvanian and Permian(?) in the area and specimens were not found in the lower Pennsylvania collections (though the genus ranges from Mississippian to Permian). Another collection (8508) assigned to the Earp because of stratigraphic position contains *Rhombopora* and *Meekopora*. *Meekopora* occurs also, with two species of undiagnostic brachiopods, in collection 8485 tentatively assigned to the Earp. This genus is long ranging (Silurian to Permian), but no examples were found in collections from the Horquilla and it is said that in the Pennsylvanian *Meekopora* is "common only in uppermost Virgilian beds". [See Moore and others, 1944, p. 675.]

The Bryozoa (*Fenestella*, *Rhomboporella*, and *Rhombotrypella*) in collection 8933, which is doubtfully referred to the Earp, are very much like those in Lampasas (*)-Des Moines faunas.

The Earp of the Dragoon quadrangle contains much more distinctive bryozoans with definite Permian affinities, especially the genera *Fistulotrypa* and *Stenodiscus*, which were not found in the Tombstone area, as well as *Fenestella*, *Polypora?*, *Septopora*, and *Rhombopora?*. This may mean that there is a longer section of Earp in the Dragoon quadrangle.

J. Brookes Knight states, regarding the Earp gastropods—

Although both *Amphiscapha* and *Glabrocingulum* are known to reach into beds of at least early Leonardian age, they are both rare in the Permian. Both are exceedingly abundant in American Pennsylvanian; hence the above suggest, but do not prove, Pennsylvanian age. Neither the genera nor the compared species (*Amphiscapha catilloides*) are of value for placement within the Pennsylvanian so far as now known. The Earp, of course, could be of Wolfcamp age too. The evidence of the gastropods is negative.

Two lots of trilobites were collected from beds of Earp age and submitted to Weller, who identified them as belonging to a single species of *Ditomopyge*, a Pennsylvanian-lower Permian genus.

A larger series of Earp collections from the nearby Dragoon quadrangle has recently been studied. The section of the Earp formation appears to be longer and to contain more recognizable zones than sections in the Pearce and Benson quadrangles. Zones of rather definite late Pennsylvanian and Wolfcamp (Permian?) age have been recognized in the Earp of the Dragoon quadrangle, the Wolfcamp zone being in the upper part of the section there.

COLINA AND EPITAPH FAUNAS

The most striking faunal characteristic of the Colina is the large number of echinoid spines and the large number of gastropods, which are commonly shown by cross sections. Brachiopods are less common than these two classes and are more frequently seen in the upper part of the formation than in the lower part. The evidence from the gastropods as interpreted by J. B. Knight suggests to him that the Colina is of Wolfcamp age [Permian(?) of U. S. Geological Survey usage], but the presence of a certain brachiopod assemblage in the upper part of the formation, together with the occurrence there of a species of *Perrinites*, suggests to the writer that beds in the upper part are possibly of Leonard age. The gastropod evidence for the Wolfcamp age of the Colina is based largely on the abundance of specimens of *Omphalotrochus obtusispira* (Shumard) and on several other gastropods discussed later in this report by Knight. The brachiopod assemblage contains such species as *Dictyoclostus* cf. *D. ivesi* (Newberry), *D. occidentalis* (Newberry), *Derbyia multistriata?* (Meek and Hayden), *Meekella pyramidalis* (Newberry), *Composita mexicana* (Hall) and *Wellerella?* cf. *W. texana* (Shumard).

The fact that genera and species of gastropods thought to be of Wolfcamp age occur in the same collections with genera and species thought to suggest post-Wolfcamp age implies that the range of one or the other groups must be extended and that the fauna as a whole is a unit. It could be interpreted to mean that the Colina was a unit of either but not both Wolfcamp and Leonard(?). Another view would be that the general features of this fauna extend across the Wolfcamp–Leonard age boundary. The writer believes that the entrance of the brachiopod fauna in the middle and upper part of the Colina and the presence of *Perrinites* there is significant enough to justify the designation of the upper part as of Leonard(?) age.

The Epitaph fauna is not so large or varied as the fauna of the Colina, but nearly all of the species that occur in it are forms also found in the upper part of the Colina. It is here tentatively considered to be of Leonard(?) age although like the Colina it may possibly be Wolfcamp.

The faunas represented in the Colina and Epitaph formations were recognized as early as 1904 by Girty and have since been recognized by paleontologists generally as being of ages similar to those of the upper Hueco or, by some, to possibly younger beds. The Naco was thus early known to have had at least two faunas, the upper one of which was referred to the upper Pennsylvanian for a long time because it was also in the Hueco limestone which was considered to be of Pennsylvanian age. If one clings to the point of view of many Russian geologists familiar with the problems of the Carboniferous–Permian boundary, the well-known upper Hueco fauna would still be placed in the upper Carboniferous. The Hueco has been divided several times and restricted from its original meaning, and the beds older than those now thought to be equivalent to the Wolfcamp and Leonard(?) have been taken from it. Within the last decade P. B. King and others have suggested that the upper part of the remaining Hueco may be of Leonard age. This view was stated by P. B. King (1942). When Girty correlated the upper Naco in general terms with the upper Hueco, he was much impressed with the resemblances of the gastropods of the two formations. However, after *Dictyoclostus ivesi* var. *bassi* (*Productus ivesi* of Girty's usage) and several other fossils characteristically of Kaibab age were found in the upper Naco, he remarked on the seeming conflict between the brachiopod and gastropod evidence. Recent studies of the gastropods of the Hueco and related formations by J. Brookes Knight have led him to the belief that the principal gastropod fauna suggests a Wolfcamp age. As cited by P. B. King (1942), paleontologists other than Knight are largely responsible for the concept that some beds now included in the upper Hueco are probably of Leonard age. The correlation of the upper Colina and Epitaph faunas with the Leonard is not too strongly held because (1) there is a dearth of diagnostic fossils in certain sections, (2) some of the faunal evidence is conflicting and the true stratigraphic significance of some important fossils (heretofore generally considered to be index fossils) is not as definite as it formerly was thought to be, (3) several of the species are only tentatively identified because of incomplete material, (4) some of the species are very closely related to forms in the Wolfcamp or Word, (5) the age ranges of certain stratigraphic standards for comparison (such as the Hueco) are not adequately known nor universally agreed upon, and (6) the stratigraphic limits of some of the standards of comparison have been changed several times to attempt to make these units faunal units rather than lithologic units.

The possibility that even the upper Colina fauna is a peculiar phase of the Wolfcamp cannot be entirely ruled out; but the combination of evidence from several classes, though each is imperfect, joins in such a way as to make a Leonard age assignment for the upper Colina the best on the evidence available. Continued work on the faunas of the Wolfcamp, Leonard, and Word formations by members of the United States National Museum, United States Geological Survey, and other organizations is revealing additional closely related forms and extending the stratigraphic ranges of other species, thereby drawing the faunas closer together and making definite age assignments more and more difficult.

The faunas of the Colina and Epitaph, especially that of the Colina, are characterized by large numbers of low-spired gastropods and by echinoid spines. Fusulinids are common and fairly widely scattered stratigraphically, and their study might have contributed important age data, but unfortunately all of the fusulinid collections from the Colina and Epitaph formations in the Pearce and Benson quadrangles were misplaced or lost. None were obtained from beds of this age in the nearby Dragoon quadrangle.

Brachiopods, though relatively inconspicuous, form a very important and diagnostic element in the faunas, and there are also important bryozoans. Trilobites are few and not closely diagnostic of age.

Faunal lists from collections that serve to give a general idea of the important elements in the Colina are listed below.

Collection 8490, from an altitude 4,650 feet on west slope of Government Butte in NE¼, sec. 19, T. 21 S., R. 23 E., from upper part of Colina

Echinocrinus cratis? (White)
Echinocrinus trudifer (White)
Echinocrinus sp.
Wellerella? cf. *W. texana* (Shumard)
Derbyia multistriata? (Meek and Hayden)
Strophalosia? sp. undet.
Dictyoclostus occidentalis (Newberry), n. var. A
"*Productus*"? sp. indet.
Pelecypods, 3 species, undet.
Goniasma? sp. indet.
Naticopsis sp. indet.
Ditomopyge? sp. undet.

Collection 8503, from about 15 feet stratigraphically below BM 5700 on top of Government Butte, in T. 21 S., R. 23 E., from upper part of Colina

Echinocrinus
Wellerella? cf. *W. texana* (Shumard)
Dictyoclostus sp. undet.
Pelecypods, 4 species, undet.
Plagioglypta? sp. undet.
Goniasma? sp.
Omphalotrochus n. sp. A (very large)
Anomphalus n. sp.
Naticopsis sp. indet.
Gastropod, n. gen. B, n. sp. A
Orthonema? sp. indet.
Meekospira sp. indet.
Gastropod, n. gen. A, n. sp.
Gastropod, n. gen. C., n. sp.

Collection 8505, from NE¼, sec. 7, T. 21 S., R. 23 E., from a zone in upper part of Colina

Goniasma? sp. indet.
Perrinites sp. undet.

Collection 8513, from top of 5230 foothill on line between Rs. 22 and 23 E., T. 20 S., from upper part of Colina

Echinocrinus
Composita mexicana (Hall)
Dictyoclostus occidentalis (Newberry), n. var. A
Pelecypod, 1 species, undet.
Omphalotrochus obtusispira (Shumard)
Omphalotrochus n. sp. A

Collection 8516, from low on the dip slope of ridge in the center of sec. 26, T. 20 S., R. 22 E., from upper part of Colina

Zaphrentoid coral, indet.
Composita mexicana (Hall)
Meekella cf. *M. pyramidalis* (Newberry)
Meekella? sp. indet.
Dielasma? sp.
Pelecypod, 1 species, undet.
Gastropod, undet.

Collection 8963, from type section of Colina limestone on Colina Ridge, from lower half of Colina

Echinoid spines
Crurithyris? sp. undet.
Pelecypods, 2 or 3 species, undet.
Bellerophon n. sp. A
Worthenia sp. indet.
"Murchisonia" cf. *M. gouldii* Beede
Goniasma sp. indet.
Euomphalus sp. indet.
Omphalotrochus sp. indet.
Naticopsis sp. indet.
Orthonema? sp. indet.
Ostracodes, undet.

Collection 8964, from type section of Colina limestone, from about middle of Colina

Wellerella? cf. *W. texana* (Shumard)
Composita sp. indet.
Strophalosia? sp. undet.
Dictyoclostus cf. *D. ivesi* (Newberry)
Dictyoclostus sp. undet.
Omphalotrochus sp. indet.

Collection 8973, from hill southwest of Earp Hill, half a mile north of Government Draw and ½ mile east of Highway 80, from a zone about 50 feet below top of Colina

Meekella cf. *M. pyramidalis?* (Newberry)
Strophalosia? sp. undet.
Dictyoclostus sp. undet.
Linoproductus (*Cancrinella?*) cf. *L. villersi* (Orbigny)

The coral element in the Colina fauna is relatively unimportant.

Regarding the Colina bryozoans, Miss Duncan says—

Fragments of *Septopora* and *Fenestella?* occur in several collections and one (8501) contains a type of fenestellid which is designated *"Phyllopora"* but which is probably an undescribed genus.

The Colina of the Dragoon area contains, in addition to *Septopora*, new species of large ramose Fistuliporas?, *Clausotrypa*, and *Stenodiscus*, all characteristic Permian types.

Regarding the gastropods, J. Brookes Knight (memo., June 16, 1948) says—

The outstanding genus of the Colina collections is *Omphalotrochus* (I am restricting this genus and, as restricted, it is very abundant in rocks of Wolfcampian age and exceedingly rare above). The restricted genus is highly characteristic of beds of Wolfcampian age occurring abundantly in the Central Texas Permian as high as the Lueders, in the type Wolfcamp of the Glass Mountains, in the Hueco limestone of the Sierra Diablo, the Hueco and Sacramento Mountains, the Florida Mountains and of equivalent beds in southeastern California. Indeed, its range of abundance appears to coincide throughout the world with that of *Pseudoschwagerina*.

The species of *Omphalotrochus* (as restricted) appear to be highly variable—or else there is in the Wolfcampian beds of our southwest a species-complex that I have not yet been able to resolve. Omitting the genotype, *O. whitneyi*, of the McCloud formation of Northern California, there is only one described species, *O. obtusispira* (Shumard). The Colina forms appear to be *O. obtusispira* or varieties of that species, and these and other varieties occur throughout the Wolfcampian beds of the southwest. They are quite distinct from the only species I know from post-Wolfcampian beds. Hence, *Omphalotrochus obtusispira*, typical and varietal, is a very important factor in my belief that the Colina is of Wolfcampian age.

In addition to the evidence of *Omphalotrochus obtusispira*, there are other gastropods that strengthen the Wolfcampian assignment of the Colina. For example *Yunnania* sp. A is very close to a species abundant in the middle Hueco and the Talpa. I know no similar species in Leonardian beds. Again "new genus B sp. A" is identical with an undescribed Talpa form; "new genus A sp. A" seems to be the same as a form abundant in the middle Hueco but it is too poorly preserved for positive identification. New genus C sp. A likewise occurs in the middle Hueco. The same may be said for the species tentatively identified as *Taosia crenulata* (Girty). *Euomphalus* n. sp. A is abundant throughout the Wolfcampian beds of the southwest. Although it occurs in younger beds it seems relatively rare. It seems abundant in the Colina. Supporting the Wolfcampian assignment are the genera *Meekospira*, *Anomphalus* and *Microdonia*, which are characteristically Pennsylvanian. Although the first two are abundant in Wolfcampian beds, none of them have been met with above.

On the other hand, there are several elements which, if taken alone, suggest a younger age. Thus, *Murchisonia* cf. *M. gouldii* Beede has been regarded hitherto as a Capitan species. Likewise *Euomphalus* sp. B seems to be a species I have met before only in the high Leonard and lower Word of the Glass Mountains. The *Goniasma* reported is too poor for identification but resembles more closely a Leonardian representative of the genus than known Wolfcampian ones. However, these occurrences are overwhelmed by the mass of evidence pointing to the Wolfcampian age.

Knight further states in the same memorandum—

In making this report [on the gastropods of the Colina and Epitaph] I am focusing on the gastropods alone. I known nothing of any other elements of the fauna or of the stratigraphic sequence. However, I repeat that the gastropods argue for the assignment of the Colina and Epitaph to the Wolfcamp. . . . About a year ago [when] I reported to you on the gastropods of the area near Tombstone . . . I felt inclined to regard both [the gastropods of the Colina and Epitaph] as lower Leonardian with the reservation that both could be Wolfcampian without serious jarring loose of fossils from previously known ranges. As you know, very little has been published on Permian gastropods and I was comparing the Tombstone gastropods with the large collections of Permian gastropods now being assembled at the U. S. National Museum on which, however, only preliminary work has been done. . . . I was particularly impressed by the similarity of the gastropods of the Colina and Epitaph with those of the marine Permian of central Texas, particularly with those of the Clyde and Lueders. I had not then proceeded far with my studies of the central Texas Permian snails and was then accepting the dictum . . . based on supposed tracing of an unconformity . . . that the Belle Plains, Clyde and Lueders of that region were of Leonardian age. A month or so later, however, I had progressed to the point where I had been compelled by the close similarity and general identity of the gastropods of north-central Texas with those of the Hueco limestone of Wolfcampian age and almost complete lack of Leonardian forms to recognize that the north-central Texas Permian up to and including the Lueders is also of Wolfcampian Age. This conclusion was subsequently supported by Miller and Youngquist, 1947, and by Miller and Purizek, 1948, working with the ammonoids. As a result of this readjustment in the determined age of the faunas used as standards of comparison I was forced also to readjust my conclusions on the Colina and Epitaph of the Tombstone area. . . . I have reviewed the gastropod collections of the Colina and Epitaph in the light of my continued studies on the Permian gastropods of north-central Texas, the Glass Mountains, the Hueco and Sacramento Mountains. As a result I feel even more strongly that those parts of the Colina from which the gastropods came and the Epitaph are to be correlated with the middle (and perhaps upper?) Hueco limestone and with the Belle Plains, Clyde, and Lueders of central Texas. As stated above all of these seem to be of Wolfcampian age. I have too little evidence to say whether or not the lower part of the Hueco limestone and of the central Texas Wolfcampian beds have equivalents in the Tombstone area. Likewise so far I lack gastropods from the highest Hueco for comparison. The gastropod faunas I have of the beds discussed above show affinities to those of the Leonard of the Glass Mountains or of the Bone Springs of the Sierra Diablo region of west Texas.

The brachiopod fauna of the Colina as represented in our collections is not large. Species that have been identified in several collections are a *Wellerella* cf. *W. texanus* Shumard, *Composita mexicana* Hall, a *Meekella* cf. *M. pyramidalis* (Newberry), a new variety of *Dictyoclostus occidentalis* (Newberry), a *Linoproductus* (*Cancrinella*) cf. *L. villersi* (D'Orbigny) and a *Strophalosia* (*Heteralosia*) cf. *S. slocomi* (King). Other forms that occur are a *Dictyoclostus* cf. *D. ivesi* (Newberry) and a *Derbyia multistriata* (Meek and Hayden). The two species of *Dictyoclostus*, the *Derbyia multistriata*, and the *Linoproductus* have been recognized in the collections only from beds that so far as known occur in the upper half of the Colina. The *Wellerella* and the *Composita* range from near the base to the top.

All of the brachiopods mentioned above, except the *Strophalosia*, suggest beds that are of Wolfcamp or younger age. Many of them suggest post-Wolfcamp more than Wolfcamp.

The fact that the brachiopods that suggest post-Wolfcamp most strongly (*M. pyramidalis*, *Dictyoclostus ivesi*, *D. occidentalis*, *Derbyia multistriata*), are found in these collections only from beds in the upper half suggests to writer that possibly the same situation as is said to exist in the Hueco limestone exists here. In the Hueco limestone of the Hueco Mountains, as currently delimited, the upper part is said to be possibly Leonard and the lower part Wolfcamp (King, 1942 p. 557, 560). The fact that so many of these species are represented by varieties or by uncertainly identified specimens decreases their age significance, and the uncertainties now existing regarding the limits and content of the various units in west Texas makes a definite age decision very difficult. The brachiopods bear a stronger resemblance to those in the Kaibab (s. l.) than to brachiopod faunas of the west Texas regions.

Regarding the specimen identified as *Perrinites*, A. K. Miller (letter, Feb. 6, 1947) says, "Collection 8505 contains one silicified specimen that is almost certainly referable to *Perrinites* and therefore is most probably Leonard in age." This collection was made in the NE¼ sec. 7, T. 21 S., R. 23 E.

Two trilobites, both referred questionably to *Ditomopyge*, were identified by J. Marvin Weller from collections referred to the Colina.

Because of Knight's views on the gastropods and because of the seeming suggestion of the brachiopods and one cephalopod that the middle and upper part is Leonard or younger, we will here consider the Colina to be Wolfcamp and Leonard(?) in age.

Fossils are rarely seen in the Epitaph, and a few collections are all that we have. This dearth of fossils is due in part to a relatively small area of surface exposure, but it is also in part due to the small proportion of beds that are fossiliferous. Fossils are especially rare in the dolomite beds or zones of the formation, the red shales, and the conglomerate beds, where paleoecological conditions probably prevented the existence of profuse life assemblages.

The following are collections from a stratigraphic section of Epitaph dolomite measured on dip slope of Colina Ridge, west of Epitaph Gulch, 1 mile south of Horquilla Peak.

Collection 8515, from unit 1 of stratigraphic section on page 45 from a zone in a blue limestone 103 feet thick at top of formation

Neospirifer sp. undet.
Composita mexicana (Hall)
Dictyoclostus? sp. undet.
"*Productus*" sp. indet.

Collection 8966, from unit 18 of stratigraphic section on page 45

Composita mexicana? (Hall)
Dictyoclostus cf. *D. occidentalis* (Newberry)
Gastropod n. gen. Z, n. sp.

These collections are from Epitaph dolomite but not from measured sections given in this report. For locality data, see Gilluly, Cooper, and Williams (1954, p. 44).

Collection 8521, from zone in upper part of Epitaph

Plerophyllum? sp.
Composita mexicana (Hall)
Goniasma sp. indet.

Collection 8526

Echinocrinus
Composita mexicana (Hall)?
Yunnania? sp. B
Worthenia n. sp. A
Goniasma sp. indet.
Euomphalus sp. indet.

Collection 8527

Composita sp. indet.
Yunnania sp. B
Worthenia sp. indet.
Goniasma sp. indet.
Euomphalus sp. indet.
Omphalotrochus obtusispira (Shumard)

The fauna of the Epitaph as represented in the collections contains, insofar as they are identifiable, few forms not present in the Colina. Though not so varied, the brachiopod fauna contains two forms present in the Colina, *Dictyoclostus* cf. *D. occidentalis* and *Composita mexicana*. The *Dictyoclostus* occurs in the upper part of the Colina in the fauna that the writer believes is probably the equivalent of the Kaibab (possibly the Toroweap Division of McKee) and of the upper part of the Hueco. The other brachiopods in the collections are not definitely determinable as to species and some of them not as to genus.

Knight (memo., June 16, 1948) says, regarding the gastropods of the Epitaph—

Except that there are fewer collections of fewer species, there is no present basis for distinguishing between the gastropod faunas of the Epitaph and the Colina. *Worthenia* sp. A seems to be a new element but this has little significance. The *Omphalotrochus* and several other species are the same as those of the Colina.

A single fragment of a solitary rugose coral is listed in collection 8521, from the railroad cut in the NE¼ sec. 32, T. 19 S., R. 22 E. Regarding this coral, Miss Duncan says—

It is tentatively identified as a *Plerophyllum*, a genus known from the Permian of Australia, Asia, and Russia, but hitherto not reported in North America.

Although the evidence is far from complete, it appears to the writer that the Epitaph fauna is but a slightly smaller representative of the fauna of the upper Colina. His tendency would be to refer it to the Leonard and to possible equivalency with the lower Kaibab (perhaps Toroweap of McKee). The presence in it of *Omphalotrochus obtusispira* would perhaps indicate, in the present state of knowledge, that there is evidence of a Wolfcamp age. But this evidence is, in the writer's opinion, overbalanced by the stratigraphical position of the Epitaph above the Colina, by the resemblance of the Epitaph brachiopods to forms from beds younger than Wolfcamp, and by the presence of a species of *Omphalotrochus* in post-Wolfcamp rocks as related to me in a personal communication by Dr. Knight (December 1952).

Additional collections of fossils from the Colina and Epitaph are listed in the paper by Gilluly, Cooper, and Williams (1954). These include gastropods listed in discussions in this report but not represented in faunal lists given here.

POST-PALEOZOIC–PRE-CRETACEOUS INTRUSIVE ROCKS

JUNIPER FLAT GRANITE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

In the northwestern part of the Bisbee quadrangle is a large mass of granite, originally described by Ransome (1904, p. 75–78). It is well exposed on the northeast wall of Tombstone Canyon and on Juniper Flat, which is here taken as the type locality (pl. 13). Although Ransome distinguished, in mapping, between the granite and some closely associated granite porphyry and rhyolite dikes, he believed that all were probably derived from the same magma, as several of the bodies were clearly shown to be (Ransome, 1904, 82–83). No attempt was made to separate the granite porphyry and more equigranular granite in mapping the area here described; the rhyolites, with aphanitic groundmasses, were distinguished, however, as they are clearly much younger than the granite.

In the area of plate 5 the Juniper Flat granite is exposed in two principal and half a dozen smaller areas aggregating a little more than 1½ square miles. The chief outcrops are along the south edge of the map and represent extensions of the mass mapped by Ransome on the east side of Tombstone Canyon. There are two main offshoots of this mass, one extending north for about 2½ miles from a point half a mile west of the southeast corner of the Benson quadrangle, the other lying to the east and occupying most of sec. 17 and the east part of sec. 16, T. 22 S., R. 23 E. Smaller outcrops occur in the heads of both main tributaries of the west fork of Sandy Bob Canyon and probably represent extensions of the more easterly of the large masses beneath the overlying Comanche rocks. Smaller dikes and irregular intrusive rocks cut the Pinal schist southeast of Sandy Bob Ranch and the Paleozoic rocks—including the Naco group—farther west.

Generally the Juniper Flat granite is more resistant to erosion than all the nearby rocks except the Bolsa quartzite. Accordingly, it forms topographic prominences and in many places rugged cliffs and steep slopes.

GEOLOGICAL RELATIONS

The Juniper Flat granite forms discordant intrusive masses that cut all the formations up to and including the Horquilla limestone. In this area there seems to be but slight structural control of the contacts except for a rough tendency of the mass to form sills beneath the Bolsa quartzite. The contacts with all the other formations appear to be clean-cut and without regard to preexistent structures. In the Bisbee quadrangle Ransome noted a tendency for dikes related to the Juniper Flat granite to follow faults—some of large throw. Similar features were not recognized in this area. Although the eastern contact of the main mass of the Juniper Flat granite is not exposed, the visible contacts suggest that the mass is a stock.

PETROGRAPHY

The Juniper Flat granite is light reddish brown in the outcrop and pinkish gray on fresh fracture. Although much of it along Tombstone Canyon is equigranular, most of it is porphyritic within the area of this report. However, there is a considerable range in grain size: from granite porphyry having phenocrysts 2 or 3 millimeters across in a microcrystalline groundmass to porphyritic granite with phenocrysts as much as 2 centimeters across in a groundmass composed of grains one-half millimeter in diameter.

In hand specimens the recognizable minerals are quartz, pink untwinned feldspar, white feldspar with albite twinning, and biotite, locally altered to chlorite. Many of the grains are somewhat rounded, though most of the biotite crystals are well-formed books. For the most part, the groundmass cannot be resolved with a hand lens, but in some specimens quartz and two varieties of feldspar can be identified.

Under the microscope the predominant mineral is recognizable as microperthite—probably all microcline microperthite, although much of it shows no twinning. The plagioclase, where fresh, is oligoclase but has been largely altered to albite flecked with sericite. Quartz is chiefly in round or embayed grains. Biotite forms euhedral books, where unaltered, but is generally slightly or wholly chloritized and epidotized with secondary sphene intercalated in the books. Muscovite is locally present, presumably as pseudomorphs after biotite. Accessory magnetite, zircon, and apatite occur; the apatite shows a marked smoky color parallel to the vertical axis. Ransome found considerable tourmaline in the rock from parts of the Bisbee quadrangle, but none was found in the specimens from this area.

The mineral compositions of analyzed specimens of the granite and granite porphyry were computed by Ransome (1904, p. 78, 82) using the chemical analyses as guides. His results were as shown in the following table. These conform well with the estimates made from study of thin sections collected during this survey, except that there seems to be an intermediate proportion of oligoclase in the rocks from this area.

Analyses of granite and granite porphyry

Granite porphyry	Percent	Granite	Percent
Quartz	42.78	Quartz	34.68
Orthoclase molecule	50.04	Microperthitic orthoclase	41.00
Albite molecule	2.10	Oligoclase (Ab_4An_1)	21.36
Hematite, magnetite, water	5.08	Biotite, tourmaline	2.96
Total	100.00	Total	100.00

The texture of the rock ranges from almost equigranular granitic (hypidiomorphic) to porphyritic with a micrographic groundmass. The phenocrysts are commonly slightly indented by the small crystals of the groundmass, suggesting attack of the residual magma at a late stage in the consolidation of the rock.

CHEMICAL COMPOSITION

Ransome (1904, p. 77) reported the following chemical analyses of granite and granite porphyry from the Bisbee quadrangle. The Juniper Flat granite, as represented in this area, would probably yield an analysis intermediate between these.

Analyses of alkali granite and granite porphyry

[Specimen data: 1, Tourmaline-bearing alkali granite, 5 miles northwest of Bisbee, Ariz. George Steiger, analyst. 2, granite porphyry sill, 3¼ miles north of Naco Junction, Ariz. George Steiger, analyst]

	1	2
SiO_2	75. 86	76. 81
Al_2O_3	12. 17	10. 96
Fe_2O_3	. 85	1. 18
FeO	. 36	. 08
MgO	None	. 14
CaO	. 62	None
Na_2O	3. 60	. 26
K_2O	5. 04	8. 50
H_2O	. 27	. 48
H_2O+	. 72	1. 17
TiO_2	. 21	. 13
CO_2	None	None
P_2O_5	Tr.	Tr.
MnO	None	None
	99. 70	99. 71

AGE

The Juniper Flat granite is known to be of post-Pennsylvanian age, for it invades the Horquilla limestone and has altered it to hornfels along the contacts. Inasmuch as there are no recognized angular unconformities within the Naco group and the pattern of the intrusive contact with the Horquilla suggests that the series had been strongly deformed prior to the intrusion, the Juniper Flat granite is regarded as post-Paleozoic.

In the northern Mule Mountains east of Sandy Bob Ranch, the basal beds of the Morita formation and the Glance conglomerate (the basal conglomerate of the Bisbee group) rest directly on an erosion surface carved into the Juniper Flat granite. Pebbles of the granite are recognizable in these beds, and there can be no question that the granite is older than the Glance conglomerate. Inasmuch as the Bisbee group is of Comanche age, this places the intrusion of the Juniper Flat granite at some time in the interval between the close of the Paleozoic and the Comanche—namely, in Triassic or Jurassic time. Apparently no closer dating can be made at the present time.

This age assignment is the same as that made by Ransome (1904, p. 84) and is well established. However, Ransome based his assignment of the age in part on the relations of the Sacramento Hill intrusion at Bisbee, which he regarded as comagmatic with the Juniper Flat granite and which he believed to be overlain with depositional contact by the Comanche rocks. However, Tenney (1936, p. 225–226) believes that the Sacramento Hill intrusion cuts the Cretaceous rocks and that the Juniper Flat mass is older and is pre-Cambrian.

Within the area of the Bisbee quadrangle, the Juniper Flat granite does not come in contact with rocks younger than the pre-Cambrian Pinal schist. However, in the area of this survey the same mass extends with intrusive contacts into the limestones of the Naco group. It is accordingly definitely not pre-Cambrian. That it is not post-Comanche is equally clear from the occurrence of pebbles derived from it in the Glance conglomerate. Hence, if Tenney is correct in interpreting the Sacramento Hill mass as intrusive in the Cretaceous, it is clear that the two masses cannot be comagmatic. Inasmuch as post-Comanche rhyolitic intrusive rocks are known in the area of this survey (see p. 106), it seems entirely likely that silicious intrusions of two ages also occur in the Bisbee quadrangle. I have made no studies of the intrusions of the Bisbee quadrangle and can offer no new evidence regarding the Sacramento Hill mass.

GLEESON QUARTZ MONZONITE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The rock to which the name Gleeson quartz monzonite is here applied crops out over an area of nearly 30 square miles, in Tps. 19 and 20 S., Rs. 24 and 25 E., in the southern part of the Dragoon Mountains, and in the pediment to the south and east of it. The town of Gleeson is at the eastern side of the mass, and the Gleeson-Tombstone road crosses it near its center.

The main facies of the Gleeson quartz monzonite is relatively poorly resistant to erosion and breaks down on weathering to angular fragments of sand size. It is thus readily eroded under the climatic conditions prevailing in this region and forms a subdued topography in which pediments have been widely carved. The low hills that rise in rounded forms above the pediments are mainly sustained by dikes of quartz porphyry or andesite porphyry, by masses of included hornfels, or by quartz veins. In resistance to erosion an alaskitic facies of the quartz monzonite, which was at first interpreted as a distinct formation, is in marked contrast to the main body. This facies forms a conspicuous ridge whose summit reaches 6,490 feet in altitude in sec. 26, T. 19 S., R. 24 E., just east of the Bar O Ranch. A smaller mass of this facies forms a band about a mile long on the north flank of Signal Hill, in secs. 15 and 16, T. 20 S., R. 24 E.

STRUCTURAL RELATIONS

Nearly all of the contacts of the Gleeson quartz monzonite are with alluvium or are faults. However, there are definite overlaps of some of the quartz latite tuff of the S O volcanics on an irregular topography cut on the surface of the quartz monzonite in sec. 33, T. 19 S., R. 24 E. and in sec. 12, T. 20 S., R. 24 E. Near South Pass the Gleeson quartz monzonite cuts the Pinal schist and holds many inclusions of altered schist both there and over much of its extent to the south and southeast. Inclusions large enough to be mapped on the scale of plate 5 occur in a belt extending south from South Pass along the western foothills of the Dragoon Mountains and curving southeast to a terminus near the Tombstone highway about 2 miles west of Gleeson. Other large inclusions that are almost certainly of Pinal schist occur about 2 miles northwest of Gleeson and at Signal Hill. The only rocks younger than Pinal that have been recognized among the inclusions are of Bolsa quartzite (doubtful) and Abrigo limestone. A knob of quartzite surrounded by hornfels that probably is derived from Pinal schist rises slightly above the pediment just north of the Tombstone road 2¼ miles west of Gleeson. The association of the quartzite with the probable Pinal makes it seem likely that it is Bolsa, though it must be confessed that altered sandstones of the Bisbee formation are difficult or impossible to distinguish from Bolsa quartzite in small masses. Hornfels that is almost certainly derived from Abrigo limestone (which retains characteristic banding even under severe metamorphism) is found in a prospect pit near this quartzite mass, but its contacts are not exposed. Two other bodies of somewhat altered limestone and shale derived from the Abrigo were found in the SW¼ sec. 30, T. 19 S., R. 25 E. One, with an apparently vertical dip, forms a belt about 10 feet wide and 700 feet long trending N. 45° W., parallel to and alongside of a felsite dike that cuts the Gleeson quartz monzonite. This belt of limestone is not severely metamorphosed and might be interpreted as a fault sliver that has merely been slightly altered by the dike that followed the fault. However, about 800 feet to the southwest of this belt, there is a somewhat shorter one, nearly parallel to it. This has definite frozen contacts with the Gleeson quartz monzonite and can hardly be interpreted as other than a normal inclusion, although it, too, is cut by dikes. The dikes at this locality trend northeast, normal to the trend of the inclusion, and are of trivial width. The metamorphism of the Abrigo limestone is no more intense alongside the dikes than it is 100 feet away. Accordingly, it is concluded that the Gleeson quartz monzonite is of post-Abrigo age. The uniformity of the Paleozoic sections throughout the map area strongly indicates that if the mass is post-Abrigo it is also post-Paleozoic.

The exposed boundary of the Gleeson quartz monzonite from South Pass to Sugarloaf Hill is the Dragoon fault, and no definitely intrusive contacts of this formation were seen along it. Along much of this distance the quart monzonite has been mylonitized and brecciated for many feet in the hanging wall of the fault.

MODE OF EMPLACEMENT

The fault contacts with most of the preintrusive rocks make it impossible to determine the relation of the mass to the preexistent structure. There is so little system to the foliation of the Pinal schist in general that it gives few clues to the preintrusive structure. It is perhaps noteworthy, however, that at the contact of the Pinal schist and the Gleeson quart monzonite west of South Pass, there is no apparent tendency for the foliation of the schist to lie parallel to the intrusive boundary. As far as it goes, this suggests emplacement by permissive rather than forceful processes—a suggestion strengthened by the abundance of hornfels inclusions within the quartz monzonite. The pervasive shearing that has affected the intrusion may have destroyed an original systematic arrangement of these inclusions, but there is no suggestion that the intrusive rocks on the two sides of such belts of inclusions differ significantly either in composition or structure. A possible exception is found along the west side of the Dragoon Mountains between South Pass and the Gleeson–Tombstone road. The rocks referred to the Gleeson quartz monzonite west of the strip of Pinal schist inclusions seem to contain slightly higher proportions of dark minerals than those to the east, though the difference is not great. The inclusions seem more likely to be stoped blocks rather than disrupted screens between separate intrusive bodies, but this cannot be said to be proved.

PETROGRAPHY

There are three main facies of the Gleeson quartz monzonite: two that differ chiefly in the obvious alteration that has affected one and not the other and a third that differs from the other two in being practically devoid of dark minerals. The first two facies—here collectively called the main facies—are so intimately associated that no attempt was made to distinguish them in mapping; but the third, the alaskite, is separately indicated on the map, though it is believed that it does not differ essentially from the other two facies in its relationships.

The main facies of the Gleeson quartz monzonite is a coarse-grained light-gray rock that ranges to greenish gray where it has been highly chloritized and to pink where it contains sufficient pink microcline. Weathered surfaces are commonly rusty brown. In hand specimens of the least altered rocks, plagioclase, microcline, quartz, hornblende, biotite, and commonly sphene can be readily recognized. The plagioclase crystals range in length from 3 to 15 millimeters and average about 5 millimeters; pink feldspar crystals range from 1 millimeter to as much as 10 centimeters in diameter and average about 5 millimeters; quartz forms grains of about the size of the plagioclase crystals. Hornblende crystals are commonly 5 to 10 millimeters long and are subordinate to conspicuous books of biotite that are as much as 10 millimeters high and 6 millimeters across. Yellow wedge-shaped crystals of sphene as much as 5 millimeters long are not uncommon. Much of the microcline is euhedral, and cleavage faces show abundant inclusions of the other minerals of the rock.

Most of the outcrops of the main facies of the quartz monzonite are cut by shear zones, and brecciation is conspicuous through the mass. This crushing is probably largely responsible for the ready weathering of the rock into sandy debris.

Microscopic examination shows that, despite the variable appearance of the main facies of the quartz monzonite both in outcrop and hand specimens, it is geologically a unit; its variations in appearance from place to place are due to postmagmatic or late magmatic changes. Evidence of such changes is found in most of the rocks of the formation; the only specimens in which it is not conspicuous or is lacking were collected from near Gleeson and scattered localities within an area extending about 2 miles southwest and roughly the same distance to the northwest of the town. Even here highly sheared and altered rocks are intimately associated with the less altered rocks, and no sharp boundary can be drawn between the primary and the altered facies of the quartz monzonite.

The microscope shows that the least altered specimens contain plagioclase zoned from about An_{55} to An_{25}, with an average composition of about An_{35}. Even in these specimens some sericite in an albite base has been formed in the cores of the plagioclase. Quartz and microcline-microperthite that contains patches and strings of oligoclase are both abundant. Hornblende—with X, light yellow; Y, yellowish green; and Z, bluish green, extinction angle 21°, $Z \wedge \acute{c}$; optically negative—and biotite, strongly pleochroic in brown and with notable amounts of apatite and sphene formed between the leaves, are the most abundant dark minerals. Biotite is generally more plentiful than hornblende. Large crystals of sphene, as much as 3 or 4 millimeters and commonly more than 1 millimeter long, and stumpy thick-set crystals of apatite are notably abundant accessories, along with magnetite. Zircon and rutile were noted but are sparse. The microcline commonly encloses the minerals other than quartz poikilitically and locally seems to have crystallized later than the quartz, thus giving the rock a monzonitic texture. Even in the same thin sections, however, other parts show quartz that encloses microcline, yielding a normal granitic texture. The range in the proportions of the light minerals is considerable. Some specimens are practically quartz-free monzonites, with about equally abundant microcline and plagioclase, others are highly quartzose. The microcline to plagioclase ratio ranges from about 3:1 to 1:3. However, in the bulk of the rock, quartz, microcline, and andesine, are about equally abundant; and the rock is clearly a quartz monzonite

The alteration of the main facies of the quartz monzonite is variable. Practically all stages can be recognized, from the nearly unaltered normal igneous rocks just described to completely recrystallized gneissic rocks, though most of the formation is crystalloblastic-cataclastic in texture and some parts are practically entirely cataclastic and grade into true mylonites.

The earliest stage in the alteration seems to be the crushing of the rock along zones that are rather widely separated on the scale of a thin section. Along the crush zones the feldspar has been saussuritized with the development of sericite and epidote or zoisite in an albitic base, and first the hornblende and then the biotite have been replaced by chlorite, with or without accompanying muscovite and calcite. In the mildly altered rocks the crystal forms of both the primary dark minerals can be recognized, but with more deformation the hornblende forms are the first to vanish and finally even those of the original biotite are destroyed and the chlorite sheaths the shear surfaces or is distributed in apparently random wisps through the rock. It is also apparent that there is not nearly as much chlorite in the most severely deformed rocks as there is biotite and hornblende in the fresher rocks. In many of the rocks muscovite is in parallel intergrowths with chlorite, replacing biotite. Also, in the more crystalloblastic specimens, it makes up large, well-formed plates within and adjoining crystals of water-clear albite (optically positive, N less than canada balsam, extinction angle 16° in the zone normal to 010). Apatite and sphene show both abrasion and corrosion in the more altered rocks but are found in notable amounts in all the specimens of the formation.

Although most of the rocks have been somewhat recrystallized and crystalloblastic textures have been developed, practically none are free from cataclastic features. The quartz is generally fractured and shows "strain-shadows," though in a few specimens evident fractures are confined to the plagioclase and both the microline and quartz have been healed by recrystallization. That there has been a beginning of metamorphic differentiation within the formation is indicated by the erratic distribution of quartz, microcline, and plagioclase, as well as by the notably diminished amount of chlorite present in the more crystalloblastic specimens. In some of the thin sections nearly all the plagioclase is in bands between layers that consist almost wholly of microcline and quartz; in others the quartz is largely confined to certain layers. All trace of an original igneous texture is absent from such rocks, though the banding is not so definite that the rock would be called a gneiss. It seems probable that the deformation of the rock was accompanied by the permeation of heated solutions through it. These solutions carried out most of the constituents of the dark minerals and the calcium from the hornblende, much of the sphene, and the anorthite component of the plagioclase and at the same time promoted the recrystallization of the rock. However, only locally did the recrystallization continue after deformation ceased, and brecciation of the crystalloblastic rock is still evident nearly everywhere.

The alaskitic facies of the Gleeson quartz monzonite, despite locally abrupt boundaries with the main facies, is believed to be an end product of the same kind of metamorphism as has affected most of the main facies. The largest mass of alaskite is an irregular body forming the south end and southwest slopes of the main ridge of the Dragoon Mountains in T. 19 S., R. 24 E. Another considerable body occurs along the north side of Signal Hill. Numerous much smaller bodies of nearly or quite identical rock are sporadically distributed within the main facies.

The alaskite facies is much more resistant to erosion than the main mass of the Gleeson quartz monzonite and forms steep, craggy slopes that differ greatly from the rolling topography developed on the main facies. Its pale-gray, almost white, outcrops contrast with the rusty hues of the rest of the formation.

The eastern and part of the southern boundaries of the main alaskite body of the Dragoon divide are abrupt, and the contrasts between the rocks on either side are very marked. However, these contacts are clearly faults, with slickensided and polished surfaces well exposed; elsewhere, both on the west and southwest sides of the alaskite mass, it is impossible to draw a sharp boundary between the alaskite and the main mass of the quartz monzonite because the gradation between them is complete.

Several of the smaller bodies of alaskite are linear in outcrop, thus suggesting that they may be dikes, though exposures in most of the pediment are too poor to establish this. No frozen contacts or chilled borders were found, though they were sought. In their absence, the linear trend of these bodies cannot be regarded as proving their intrusive origin, because, if the alaskites are merely more completely leached of dark minerals than the main mass of the quartz monzonite, they might also be expected to have a linear distribution along shear zones. In several places these smaller masses appear to grade into the normal facies.

The many gradational contacts, the occurrence of all stages of transition between the facies, and their intimate association in many parts of the area all suggest that the alaskite bodies are not separate intrusions but merely parts of the quartz monzonite in which selective leaching of the dark minerals and coarser crystallization of the muscovite have been carried further during the metamorphism than they were in the main body.

In hand specimens the rock ranges from practically white through pale to pinkish gray. Quartz, plagioclase, microcline, and muscovite are the only minerals recognizable with the hand lens. In grain the rock ranges from fine, aplitic-appearing material to fairly coarse, with quartz grains as much as 1 centimeter in diameter, though averaging perhaps 5 millimeters, plagioclase and microline of about the same size, and muscovite plates that range from 1 millimeter to as much as 15 millimeters across.

In thin sections there is little difference between the alaskite facies and the more altered specimens of the main facies. The fine-grained, aplitic-appearing rocks owe their grain size to pulverization; all are thoroughly cataclastic. The coarser grained varieties show the megascopic minerals to have the same relations as they do in the main facies, except that the muscovite is practically all in well-individualized crystals and both apatite and sphene are much less abundant or even absent. Some specimens, however, show rounded and apparently corroded fragments of apatite that are similar, in their stumpy, thickset form, to the apatite crystals of the main facies. The textures range from almost wholly cataclastic, in the aplitic-appearing rocks, to quartz-flooded granitic in some of the coarser grained rocks. Many specimens are crystalloblastic-cataclastic but a few are apparently normal granitic rocks. Were these rocks to be named without regard to their relationship to the Gleeson quartz monzonite, they would all be called albite-microcline alaskites.

Whether the few apparently normal granitic rocks are merely unbroken but leached blocks in the brecciated quartz monzonite, as would be required if the metamorphic origin of the distinctive characteristics of the alaskitic facies is correct, or whether the alaskite is in reality a separate primary intrusion cannot be absolutely proved. The numerous apparent transitions in the field from normal quartz monzonite to alaskite, the occurrence of rocks within the normal facies that are intermediate between it and the alaskite, the textural similarities of the two rocks, and the occurrence in both of notably stumpy crystals or corroded fragments of apatite are all features that suggest a close affinity of the two rocks. Whether their differences are in part primary or are, as I am inclined to think, wholly secondary, there seems little question that the rocks are derived from the same magma, and hence it is permissible to class them as facies of a single formation.

At the sharp bend of the Dragoon thrust in sec. 18, T. 19 S., R. 25 E., the Gleeson quartz monzonite has been reduced to a mylonite. The rock here is streaked, and aphanitic pink dikelike masses penetrate the normal facies. Under the microscope, some of these finer grained rocks are seen to be wholly cataclastic and with extremely fine grain. This variety passes gradationally into slightly coarser grained material with crystalloblastic texture and this, in turn, into the normal coarsely crystalline quartz monzonite. The mylonitic streaks are too fine grained for confident determination of the component minerals, but the intermediate material resembles aplitic rock and is notably deficient in dark minerals. The mylonite is definitely associated with the Dragoon fault. Because its composition implies metamorphic differentiation, it suggests strongly both that the rocks now exposed on the hanging wall of the fault were formerly at much greater depth and that the widespread crushing of the Gleeson quartz monzonite may all have taken place at the time of the Dragoon thrusting. It is, of course, difficult to evaluate the importance of the similarity between the metamorphic differentiation exhibited by these mylonites and the evident metamorphic differentiation in the body of the main mass. How much of the alteration of the mass occurred shortly after its injection and perhaps long before the Dragoon thrusting and how much occurred at deeper levels during the thrusting cannot be determined from the data available at this time.

CHEMICAL COMPOSITION

Two specimens were analyzed, and the results appear in the following table along with the average composition of quartz monzonite (Daly, 1934, p. 15.).

Analysis of Gleeson quartz monzonite

[Specimen data: 1, Quartz monzonite from NW¼ sec. 6, T. 20 S, R. 25 E., southwest of Gleeson. Analyzed by Lee C. Peck. 2, quartz monzonite from SW¼ sec. 19, T. 19 S., R. 25 E., west of Courtland. Analyzed by Lee C. Peck. 3, average quartz monzonite]

	1	2	3
SiO_2	64.96	65.45	66.64
Al_2O_3	16.63	16.86	15.57
Fe_2O	1.99	1.89	1.91
FeO	1.92	1.84	1.94
MgO	1.54	1.25	1.41
CaO	3.78	4.35	3.50
Na_2O	3.31	3.41	3.41
K_2O	3.74	3.50	3.72
$H_2O\pm$	1.22	.38	1.15
H_2O-	.10	.09	----------
TiO_2	.46	.41	.50
P_2O_5	.24	.29	.19
MnO	.10	.11	.06
Total	99.99	99.83	100.00

The norms, according to the classification of Cross, Iddings, Pirsson, and Washington are as follows.

Average composition of quartz monzonite

Constituent	1	2
Quartz	20.88	21.42
Orthoclase	21.68	20.57
Albite	27.77	28.82
Anorthite	18.07	19.68
Corundum	.61	.20
Hypersthene fs	1.06	1.19
Hypersthene en	3.90	3.10
Magnetite	3.02	2.78
Apatite	.34	.67
Ilmenite	.91	.76
Symbol	I(1).4.″3.3″	I(1).4.″3.3(4).

As is usual, the modal feldspar is lower in anorthite (about An_{35}) than the norm, the discrepancy being accounted for by the lime component of hornblende and sphene; the corundum expresses the modal mica.

AGE

That the Gleeson quartz monzonite is post-Pinal and pre-S O volcanics in age is directly determinable from the contact relations; that it is also younger than the Abrigo limestone seems sufficiently proved by the inclusions of calc-hornfels with features characteristic of the Abrigo that are found northwest of Gleeson. (See p. 56.) To narrow the possibilities of its age further, only indirect means are at hand. The persistence and uniform thickness and lithology of the rocks of Paleozoic age of the area are such that any intrusive mass as large as that of the Gleeson quartz monzonite, if it be post-Abrigo in age, can hardly be as old as Permian. Pebbles that petrographically resemble the Gleeson quartz monzonite occur in the conglomerates of the Bisbee formation east of the Dragoon Mountains and suggest strongly that the intrusion is pre-Bisbee in age and thus of the same intrusive cycle as the Juniper Flat granite of the Mule Mountains. However, pre-Cambrian intrusive rocks similar to the Gleeson quartz monzonite (and hence to the pebbles in the Bisbee) occur north of Black Diamond Peak; and the Dragoon fault, of unknown but certainly large horizontal displacement, separates the Gleeson quartz monzonite from the Bisbee formation, so that the assignment of the intrusion to pre-Bisbee time cannot be regarded as definitely proved. This assignment is not, however, inconsistent with any facts at hand and seems sufficiently probable, so that it is here adopted as a working hypothesis.

QUARTZ MONZONITE PORPHYRY DIKES IN GLEESON QUARTZ MONZONITE

Dikes of many varieties, among them many composed of quartz monzonite porphyry, cut the Gleeson quartz monzonite mass. No attempt was made to map these bodies in detail, and neither their trends nor their distribution were carefully studied. Those noticed were widespread in the main mass of the Gleeson quartz monzonite, but none were noted in the alaskitic facies. Most are only a few tens of feet thick; none were seen to exceed 100 feet in thickness.

The rocks composing these dikes range from varieties closely resembling the main facies of the Gleeson quartz monzonite to decidedly porphyritic rocks that contain rounded phenocrysts of quartz and large crystals of feldspar in a fine aphanitic base. Mineralogically, however, these rocks are all closely related to the Gleeson quartz monzonite, and consist of saussuritic andesine, microcline, quartz, and hornblende and biotite or their alteration products, chlorite, calcite, and sericite. The proportions of the constituent minerals are about the same as in the Gleeson, and the textures of the dike rocks testify to their crushing and recrystallization in the same way as in the main intrusive mass. These dikes are accordingly regarded as belonging to the same igneous cycle as the main intrusion of the Gleeson quartz monzonite.

COPPER BELLE MONZONITE PORPHYRY

NAME

The name Copper Belle monzonite porphyry is here applied to the porphyry exposed on and near the Copper Belle claim, on the west slope of Gleeson Ridge in the Gleeson district. These rocks were not distinguished by Wilson (1927, pl. 1) from the quartz monzonite to the west, here called the Gleeson quartz monzonite. The mass of this formation at Courtland was, however, distinguished as monzonite porphyry by Ransome (1913, p. 128, 130). Petrographic study shows that the rocks of these localities are identical and differ conspicuously from the Gleeson quartz monzonite.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The outcrops of Copper Belle monzonite porphyry form a nearly complete elliptical ring on the lower slopes of Gleeson Ridge. Smaller outcrops are found in the alluvial areas to the east and northeast, and a considerable body is exposed in the Courtland district near and east of the abandoned post office. From this large body in the Courtland district, several smaller outcrops extend northwest as far as the alluvium in the northern part of sec. 17, T. 19 S., R. 25 E. West of this belt another small mass is exposed in the valley that cuts Turquoise Ridge and which was formerly followed by the wagon road west of North Courtland. Along the eastern slopes of the Dragoon Mountains north of South Pass, porphyry referred to this formation is exposed in a belt about 1½ miles long; and still farther north, an evident continuation of this mass appears in the valley of the stream that leaves the mountains about a third of a mile south of Walnut Springs. Far to the north in the thrust breccias east of Middlemarch Canyon, there are several poorly exposed masses of similar porphyry, but these are too small to be shown on the map accompanying this report.

The Copper Belle monzonite porphyry is relatively weakly resistant to erosion and generally forms low ground and gentle slopes masked with considerable rubble derived from it and the topographically higher sedimentary rocks bordering it.

GEOLOGICAL RELATIONS

The relations of the Copper Belle monzonite porphyry to the other rocks of the region are puzzling and obscure, owing both to its poor exposures and to the fact that the Escabrosa limestone, with which it has most of its exposed bedrock contacts, is so pure a carbonate rock that it is not favorable to the development of contact metamorphic minerals even along intrusive contacts. Accordingly, the prevailing absence of hornfels along the border of the porphyry does not demonstrate that the contacts are not intrusive.

All exposed contacts in the Gleeson district are faults. Several outcrops and prospect pits along the contact of the porphyry and Escabrosa limestone on the northeastern and eastern sides of Gleeson Ridge show that low-dipping faults accompanied by breccia separate the two formations. Faults roughly parallel to this contact occur both higher on the hill, within the Escabrosa and Horquilla limestones, and lower, within the monzonite porphyry. A low-dipping fault within the porphyry, about 100 feet vertically below the limestone plate, is accompanied by a breccia about 5 feet thick that contains angular fragments of limestone, porphyry, and quartzite, intimately ground together and showing no signs of igneous metamorphism such as would be expected in an intrusive breccia. Although this breccia disappears into the talus after only a few score feet of exposure along the strike, no doubt exists that it is there. The monzonite porphyry is also bounded by exposed low-angle faults at many other places: at the southeast end of Gleeson Ridge, just north of the abandoned railroad grade; on the northwest flank of the hill just to the southeast of Gleeson Ridge, east of the railroad grade, where the contact is exposed in several prospect pits and adits; at several points along the north and northeast contacts of the mass at Courtland; at several localities along the west and southwest sides of Gleeson Ridge, where it is overthrust by both the Sugarloaf quartz latite and rocks of early Paleozoic age.

The rocks of early Paleozoic age of this last locality contain silicates of contact metamorphic origin, but the rocks at all the other contacts mentioned show no thermal effects.

The porphyry is bounded by high-angle faults at many other places: in the long northwest-trending belt of narrow outcrops of the porphyry in the central and northwestern parts of the Courtland district, where many faults of probably slight displacement bound the several blocks; and in the area north of South Pass, where a high-angle fault separates the porphyry from the Cretaceous rocks to the east. This fault, though steeply dipping, is probably a part of the main Dragoon thrust, though it may be a younger fault that cuts the thrust sheets as many others are known to do. The west side of this porphyry mass is bounded by a steep eastward-dipping fault, clearly related to the thrusts that duplicate much of the Paleozoic section on the ridge to the west. Farther north, near Walnut Springs, the east boundary of the porphyry is clearly intrusive. Here, then, it is clear that the intrusion has moved as an integral part of the thrust sheet. (See pl. 6, sec. *X–X′*, *XI–XI′*, and *XII–XII′*.)

Near South Pass the conglomerates of the Bisbee formation contain pebbles of monzonite porphyry that closely resemble the Copper Belle monzonite porphyry which differs petrographically from all other rocks recognized in the region. This is an additional suggestion that the porphyry is of prethrust age and that the many low-angle faults mentioned near Courtland and Gleeson are really significant and not merely contacts along which only trivial movements have occurred.

Despite these evidences that the porphyry is of prethrust age, there are several features that suggest that the low-angle faults may, after all, be minor and that the porphyry reached essentially its present position, with respect to its bordering rocks, at the time of its intrusion.

In the gulch on the line between secs. 20 and 21, T. 19 S., R. 25 E. (pls. 5, 11) is a body of hornfels, probably derived from the Martin limestone. This hornfels is nearly surrounded by the monzonite prophyry which has well-exposed frozen contacts. The Escabrosa limestone along the northern boundary of the porphyry is thus in apparently normal stratigraphic succession above the Martin, despite the fact that a low-angle fault between the porphyry and Escabrosa limestone is well exposed at several places. This strongly suggests that the movement on this fault was slight. If the porphyry is of prethrust age as I have tentatively concluded, it is indeed a remarkable coincidence that the segment containing the inclusion of silicated Martin limestone participated in large-scale thrusting and then came finally to be overlain by a different thrust block in roughly the proper stratigraphic succession. This one fact might be considered as demonstrating the insignificance of the low-angle fault at the boundary of the porphyry. However, this fault farther east brings Martin limestone in contact with the porphyry, and despite excellent exposures, no signs of contact metamorphism can be detected in the Martin at this eastern locality. On the hypothesis that the fault is trivial and essentially marks the original intrusive boundary, it might be possible to attribute the lack of contact metamorphism of the Escabrosa along it to the purity of the limestone, which at many definitely intrusive contacts elsewhere in the area shows itself to be not readily susceptible of silication. The Martin, on the other hand, is a highly impure, clayey limestone and is generally altered conspicuously for long distances from intrusive contacts. Its lack of alteration here seems significant. Thus, the approximately normal stratigraphic succession shown by the two blocks may not be incompatible with considerable movement on the low-angle fault that separates them. Many of the thrust slices in the Courtland and Gleeson districts are in roughly the normal stratigraphic succession, on a gross scale, though the occurrence of blocks of widely differing ages in the breccias shows that the faults separating the several blocks had considerable movement. This may simply be another example of the same phenomenon.

Although all well-exposed contacts of the monzonite porphyry in the Gleeson area are faults, a section drawn through the now inaccessible Pemberthy and Tejon shafts by Messrs. Augustus Locke and A. S. R. Wilson (1927, p. 70, fig. 15) shows all contacts with the limestone at depth as intrusive. Thus, if the porphyry is prethrust in age, the thrust block containing its original intrusive contacts is at least 600 feet thick beneath Gleeson Ridge. On the other hand, if the porphyry is younger than the thrusting, it may penetrate several thrust sheets, which it is nowhere seen to do at the surface. Wilson (1927, p. 48–49, 72) repeatedly comments on the absence of contact metamorphism of the limestone along these boundaries and the fact that they seem merely to have furnished channels for circulation of the mineralizing solutions. It seems possible that they may be faults as are the boundaries exposed at the surface. At any rate, the same section that shows the contacts with the limestones as intrusive also shows that the porphyry (see "quartz monzonite" *in* Wilson, 1927, fig. 15) is cut off by a reverse fault that brings "rhyolite" (Sugarloaf quartz latite of this report) over the intrusive rock. In view of the association of this fault on the surface with the trend of the main thrust, there can be little doubt of its belonging to the same period as the other reverse and low-angle thrust faults. Hence, even if the contacts of the porphyry with the limestone are correctly interpreted as intrusive, there is good reason to suspect that the intrusion antedated the thrusting.

The occurrence of mineralized material in several thrust sheets at both Gleeson and Courtland, and the mineralization in both localities of many faults younger than the thrusts, shows rather conclusively that the mineralization is younger than the thrusting. Thus, the genetic connection between monzonite porphyry and mineralization, postulated by both Ransome (1913, p. 130) and Wilson (1927, p. 16), if correct, would require the porphyry to be postthrusting in age. However, as Ransome pointed out, the porphyry has been so thoroughly altered that the ultimate source of the mineralizing solutions must be put at a lower level than any rocks now exposed in the area. Mineralization seems no more closely associated with the porphyry than with any of several other formations—certainly the ores of Gleeson and Courtland are similar to those of Barrett Camp, Black Diamond Peak, and Middlemarch Canyon, at none of which localities is there any sign of monzonite porphyry resembling the Copper Belle. Accordingly, this postulate seems not to have sufficient force to require its consideration in interpreting the relations of the porphyry. Incidentally, the monzonite porphyry referred to by Wilson was not the Copper Belle of this report, which he did not distinguish from the mass here described as Gleeson quartz monzonite, but the finer grained porphyry intimately associated with the Sugarloaf quartz latite on the east slope of Turquoise Ridge (and mapped with that volcanic formation in pl. 5, although it was recognized as intrusive).

Another feature that suggests a prethrust age for the monzonite porphyry is the regularity of its contacts. No dikes are found extending out from the main masses unless the belt extending northwest through the Courtland district is considered as a dike swarm. As already mentioned, many of the porphyry masses in this belt are bounded by exposed faults. No frozen contacts nor textural changes suggesting contact chilling have been found in any of these bodies though they were carefully sought. Nor are any sills recognizable along any of the low-angle faults—a surprising lack if the porphyry were postthrust in age. Accordingly, it is believed that the low-angle thrust faults cutting and bounding the masses of monzonite porphyry should be interpreted at their face value, as indicating that the intrusion was emplaced in prethrust time.

In summary, then, it is here concluded that the probabilities favor a prethrust date for the emplacement of the monzonite porphyry, though on this hypothesis there are several anomalies that require an explanation approaching special pleading. However, the obstacles to the assumption of a postthrust age appear much greater. The assumption of a postthrust age would imply that the exposed low-angle faults, despite their resemblance in attitude and all other relations to the major thrusts, are merely small and insignificant displacements wholly unconnected with the larger faults.

PETROGRAPHY

Hand specimens of the Copper Belle monzonite porphyry differ greatly, owing to diversity of metamorphism. The porphyry ranges from light gray through buff to dark greenish gray, or even uniform pink; texture, however, remains remarkably constant in all varieties, being characterized by conspicuous phenocrysts of feldspar that range from about 1 to 10 millimeters in length and average about 6 millimeters. In some specimens sparse phenocrysts of quartz can be seen, but these only exceptionally attain 1 millimeter in diameter and in most specimens cannot be seen with a hand lens. A few specimens contain chlorite that occurs as pseudomorphs after hornblende or biotite; but in most, though much chlorite can be identified, it is present as indefinite aggregates that fail to preserve the forms of the original dark minerals. In some rocks both gray or white plagioclase and pink orthoclase are identifiable as phenocrysts, but in other outcrops only pink feldspars can be seen, and many of them give evidence under hand lens of albite twinning, as noted by Ransome (1913, p. 130). The groundmass is everywhere clearly crystalline but aphanitic.

In thin sections the rocks all show considerable alteration. The plagioclase, by far the dominant phenocrystic mineral, is invariably altered to albite, clouded with sericite and epidote, and in some specimens partly replaced along cleavages by orthoclase. There are few orthoclase phenocrysts, though there seems to be a great deal of orthoclase in the very fine-grained groundmass. The quantity of orthoclase is difficult to estimate, however, owing to the felt of sericite throughout the groundmass. Quartz is present as phenocrysts in most specimens, but the amount is very small, both as phenocrysts and in the groundmass, and is estimated as less than 5 percent of the rock. Chlorite, generally accompanied by considerable muscovite, forms pseudomorphs after amphibole, and less commonly after biotite. Some is distributed through the groundmass as irregular aggregates. The amount of green epidote differs; in some specimens there is but little present, but in others it largely replaces amphibole, biotite, and plagioclase. Clinozoisite is common in the feldspar. The accessory minerals are apatite, which forms slender prisms; magnetite; and a little sphene and zircon. Owing to the alteration that all the rocks have undergone, to estimate accurately their original composition is difficult. However, plagioclase evidently dominates the primary phenocrysts, and judging from the considerable amounts of epidote and clinozoisite present, the original plagioclase was probably rather calcic. Orthoclase, as usual, appears to be more abundant in the groundmass than as phenocrysts, and quartz is so subordinate that it is hardly an essential mineral. Probably the rock was originally a biotite-hornblende monzonite porphyry, and this is the classification here adopted.

It should be pointed out that although the rock has been highly altered by hydrothermal solutions, little or no cataclastic structure is evident. This must be regarded as somewhat surprising, if the assignment of the intrusion to a prethrust age is correct; because the other prethrust intrusive rocks, particularly the Gleeson quartz monzonite, show cataclastic or crystalloblastic-cataclastic textures in most specimens. However, the tectonic level represented by the Gleeson quartz monzonite is probably much deeper than that represented by this formation. Accordingly, it seems possible that this rock, during the thrusting, may have broken into coarse slivers like those of the accompanying sedimentary rocks (many of which show surprisingly slight internal deformation) while the Gleeson quartz monzonite was undergoing penetrative movement on a much finer scale. On the other hand, this absence of cataclastic textures might be regarded as indicative of a postthrust age for the intrusion. Reasons have been given in the preceding section of the report for rejecting this interpretation, but they may be wrongly evaluated.

AGE

The age assignment of the Copper Belle quartz monzonite has been discussed in connection with its relations to the bordering rocks, and the reasons that suggest prethrust age have there been mentioned. It clearly invades the Paleozoic rocks north of South Pass and hence must be post-Paleozoic. If the pebbles of porphyry in the Bisbee formation near South Pass have been correctly assigned to this formation, then the porphyry is pre-Comanche in age. Inasmuch as no closer bracketing of the age seems possible, the formation is here assigned to the same igneous cycle as the Juniper Flat granite and the Gleeson quartz monzonite; that is, post-Paleozoic but pre-Cretaceous. Such an assignment is further favored by the fact that the Copper Belle in the lowland north of Courtland is cut by a few dikes of quartz monzonite porphyry that resemble those that cut the Gleeson quartz monzonite to the west and differ notably from the Copper Belle in having a high quartz content.

Should it develop that the several features suggesting a prethrust age have been misinterpreted and that the formation is younger than the thrusting, assignment to some part of the Tertiary would be necessary; but this does not seem to be indicated by the data at hand.

COCHISE PEAK QUARTZ MONZONITE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The rock to which the name Cochise Peak quartz monzonite is here given crops out in a belt extending from the northern side of Cochise Peak, south-southeastward for nearly 3 miles, to the divide at Middle Pass. This belt ranges in width from about 1,000 feet to nearly half a mile. Smaller bodies identical petrographically with this, and with similar geological relations, abound in the thrust slivers on the east slopes of Cochise Peak and near the head of Middlemarch Canyon. Many of these bodies are much too small to be shown on plate 5, which is necessarily generalized in such areas. For example, the strip shown as Bisbee formation that lies west of the head of Middlemarch Canyon, between the Stronghold granite and Colina limestone, contains many slivers and blocks of this quartz monzonite, though the bulk of the fault sliver is Bisbee formation. Numerous other blocks were seen but could not be shown on the map in this area.

Three areas underlain by similar rocks also referred to this formation occur several miles to the north, near the mouth of Stronghold Canyon (Pearce quadrangle). All three of these bodies are at the contact of the Stronghold granite, so that the rock might be thought to be merely a contact variant of that intrusion except for the petrographic and structural analogies with the Cochise Peak rock.

The erosional resistance of the Cochise Peak quartz monzonite is variable owing to the local differences in crushing and recrystallization that it has undergone. Cochise Peak, one of the higher summits of the range, is composed of this rock; but farther south the rock is much more crumbly and readily decomposed, so that it forms slopes mantled with debris and capped by more resistant hornfels and quartzite.

GEOLOGICAL RELATIONS

Most of the contacts of the Cochise Peak quartz monzonite are faults and thus give little direct clue to its original intrusive relations. For example, the rock along the western boundary of the main mass extending south from Cochise Peak is much finer grained than the rock farther from the contact; and as the transition in grain size is relatively gradual, it appears to represent a chilled border facies, so that this contact was first interpreted as showing a post-Bisbee age for the intrusion. This contact appears on Cedarstrom's map (1946, pl. 1) as an intrusive boundary. However, further study shows that the finer grained material at the contact is merely more finely comminuted material and in places is a true mylonite, so that this contact, which at first glance appears to be intrusive, is also a fault as are most of the others. However, on the west side of the ridge that trends north on the west side of Middlemarch Canyon (in Soren's Canyon, not named on the map), about 1,000 feet north of the road from Middlemarch Canyon to Middle Pass, there are definite inclusions of Bolsa quartzite in the quartz monzonite, with frozen contacts and boundaries so irregular and interlocking that they are not explicable by faulting. Contacts less well exposed, but also interpreted as intrusive with the Bolsa and Abrigo, occur on the north slope of the hill just east of the divide at Middle Pass—called "The Sentinel" on Cederstrom's (1946, pl. 1) map. Several of the contacts with the Paleozoic rocks near the mouth of Cochise Stronghold appear also to be frozen, but evidence of remetamorphism of the brecciated quartz monzonite by the Stronghold granite, discussed in connection with the petrography of the formation, render the interpretation of such contacts in the vicinity of the younger intrusion highly dubious.

PETROGRAPHY

The Cochise Peak quartz monzonite is generally light greenish gray, weathering to rather dark-grayish-brown colors. It is generally spangled with conspicuous flesh-colored crystals of microcline that are as much as 4 centimeters long. In many outcrops these crystals are well formed and generally show a crude parallelism, but in others they are greatly broken and strung out. The abundance of crystals ranges greatly—only one or two to a square foot of surface in some places but in others so closely packed as to dominate the groundmass. The groundmass crystals, though somewhat smaller than 2 millimeters in average grain size, can be recognized with the hand lens as including quartz, potash feldspar, plagioclase, muscovite, and chlorite. Commonly, the boundaries of the groundmass crystals are obscure and blurred, as seen under the hand lens; and as microscopic examination shows, this is due to the crushing and partial recrystallization of the rocks. In places the rock grades into mylonites.

As seen in thin sections, the Cochise Peak quartz monzonite has been greatly altered. The plagioclase is in broken saussuritized crystals that now consist of albite crowded with minute flakes of sericite and crystals of zoisite and epidote. The microcline-perthite, the most abundant mineral, is veined and contains patches of albite but by younger veins that contain epidote. Some of the perthite crystals are poikilitic and enclose the other minerals, but these poikiloblasts have been themselves broken and the fragments have been displaced. The rock paste thus formed has been recemented by more microcline (or adularia?) that is free from smaller inclusions. Quartz is abundant and generally shows lobate contacts against the plagioclase. Although the quartz occurs as fairly clear grains, all show strain shadows, and mortar structure is nearly invariably present. Muscovite, which is in parallel intergrowth with some chlorite in most rocks and hence probably derived from biotite, is also fairly abundant. These minerals are generally much bent and broken. The common accessories are sphene, magnetite, apatite, zircon, and a little rutile. Of the dozen specimens examined, only one shows any relicts of an original granitic texture. The others are all either wholly cataclastic or crystalloblastic-cataclastic. The saussuritic plagioclase is generally somewhat subordinate to quartz and microcline, which are about equally abundant; and it is concluded that the rock was probably originally a biotite-quartz monzonite.

The above description applies in its essentials to all the specimens examined. However, many from near the contact with the Stronghold granite have been contact-metamorphosed. In many of these rocks the boundaries of the feldspar crystals as seen in the hand specimen are blurred and indistinct. On microscopic examination many of these specimens show that large plates of muscovite have been formed, with random orientation within the plagioclase crystals. Nests of chlorite are surrounded by biotite, pleochroic in brown, with sharp boundaries against the chlorite. Commonly, these biotite aggregates, which are believed to be clearly younger than the chlorite, show themselves to be composed of small randomly oriented equant crystals, nearly as thick (normal to the cleavage) as they are long. Furthermore, along the grain boundaries of the light minerals, a little augite and hornblende occur as minute crystals, many of which show uniform optical orientation around three sides of a given grain of quartz, microcline or plagioclase. They are believed to be clearly younger than the crushing of the rock and must have developed under essentially static conditions. Although these grains are very small, few being larger than 0.1 millimeter in uninterrupted diameter, their identification is believed to be correct. The augite is optically positive, with axes emergent on both (001) and (100) and with an extinction angle of 47°, $\gamma \wedge c'$.

Its indices are slightly lower than those of the adjacent green epidote. The hornblende is pleochroic, with X light yellow green, Y darker yellow green, and Z strongly bluish green, extinction angle 29°, $\gamma \wedge c'$. Some of it is in parallel intergrowth with the augite. Strangely enough, in places, these minerals are in direct contact with green epidote. Inasmuch as the rocks at a considerable surface distance from the contacts with the Stronghold granite contain veinlets of green epidote that has about the same color and distribution as in these rocks, the augite and hornblende are considered younger than the epidote, just as the biotite is younger than the chlorite. These minerals seem to be clearly the products of contact metamorphism that has been superposed upon the cataclastic metamorphism. Such a conclusion is in accord with the geological as well as the petrographic evidence.

Veinlets containing small amounts of topaz penetrate some of these contact-metamorphosed specimens. A little tourmaline is also present in them.

CHEMICAL COMPOSITION

The following is the result of an analysis of a specimen of the Cochise Peak quartz monzonite.

Chochise Peak quartz monzonite, from west slope Cochise Peak

[Lee C. Peck, analyst]

Bulk analysis		Normative minerals—C. I. P. W. Symbol: I.(3)4.2″.(3)4	
SiO_2	72.60	Q	34.86
Al_2O_3	14.22	or	16.68
Fe_2O_3	.67	ab	29.34
FeO	1.17	an	11.95
MgO	.74	c	1.02
CaO	2.60	hy {en 1.80, fe 1.19}	2.99
Na_2O	3.50		
K_2O	2.77	mt	.93
H_2O+	.88	il	.61
H_2O-	.21	ap	.34
TiO_2	.32		
P_2O_5	.15		
MnO	.07		
Total	99.90		

It may be noted that the rock is notably lower in alkalies, especially potash, and higher in lime than either of the specimens of the Stronghold granite analyzed (see p. 108). This tends to support the validity of the distinction here made between the two rocks which were classed by Cederstrom (1946, pl. 1) as parts of a single body. Because, however, the perthitic crystals that contain most of the potash are phenocrysts, it is by no means certain that the analysis correctly represents the bulk composition of the rock—in fact, if it did the rock should perhaps be called a granodiorite despite the low lime content. This classification is not made, however, because of the very conspicuous and abundant perthite phenocrysts which surely give the impression of constituting a larger proportion of the rock than the analysis suggests.

RELATION TO OTHER INTRUSIVE ROCKS AND AGE

The Cochise Peak quartz monzonite, despite its textural differences in the less-crushed facies, evidently closely resembles both the pre-Cambrian(?) quartz monzonite near Dragoon Camp and the dominantly altered facies of the Gleeson quartz monzonite in both mineralogic and chemical composition. In fact, were the rock at Dragoon Camp not in relations that suggest pre-Cambrian, little doubt exists that the Cochise Peak quartz monzonite would have been mapped as a northern representative of the Gleeson quartz monzonite. Though somewhat different in habit, the microcline poikiloblasts occur in both the Cochise Peak and Gleeson quartz monzonites. Both intrusions are known to invade early Paleozoic sedimentary rocks and are thus almost certainly of post-Paleozoic age, for the Paleozoic stratigraphic section is too uniform to permit the assumption of large scale local intrusion during the time represented by it. Both rocks are also definitely older than the Dragoon thrusting, and their relations to the Bisbee formation are not definitely established. Because the occurrence of post-Bisbee, prethrust intrusive rocks (granite gneiss near Jordan and Fourr Canyons) demonstrates igneous activity in the region during this interval and the geological relations of the Juniper Flat granite in the Mule Mountains to the south demonstrate conclusively post-Paleozoic, pre-Cretaceous volcanism also, the Cochise Peak quartz monzonite may possibly belong to either of these cycles. The widespread occurrence of pebbles of quartz monzonite in the conglomeratic members of the Bisbee formation gives some ground for preferring the assignment of the quartz monzonites to the earlier of the two cycles, though, as mentioned in discussion of the Gleeson quartz monzonite, the possible pre-Cambrian age of the intrusion from which these conglomerate pebbles were derived makes the assignment somewhat dubious. However, for the purpose of this report, this assignment is tentatively made, and the Cochise Peak quartz monzonite, like the Gleeson, is regarded as early Mesozoic.

No possibility exists that the Cochise Peak rock is a part of the Stronghold granite, for that intrusion is younger than all the thrusting which involves the Cochise Peak rocks.

TURQUOISE GRANITE

NAME

The Turquoise granite is here named from Turquoise Ridge, west of Courtland, in secs. 17, 20, and 23,

T. 19 S., R. 25 E., on the west slope of which it is widely exposed.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

On the west slope of Turquoise Ridge the sparse exposures of bedrock visible through the widespread talus and colluvial material are chiefly granite. Such outcrops occur from the southwest part of sec. 17 to the south side of Brown's Peak and across the wash to the south where they are found on the lower northern slopes of Gleeson Ridge in sec. 23, T. 19 S., R. 25 E. Similar rocks were not seen elsewhere in the area of this survey. The saddles in Turquoise Ridge north and south of Brown's Peak are cut in this rock, and it is elsewhere poorly exposed beneath the prominent scarp of Bolsa quartzite. The rock resists erosion very poorly and breaks down to yield a smoothly rounded topography.

FIELD RELATIONSHIPS

The Turquoise granite is so poorly exposed that its relations to the adjacent formations can only locally be unequivocally determined. The exposures north and south of Brown's Peak, however, clearly indicate that it intrudes the Bolsa quartzite and Pinal schist. The boundaries with the Gleeson quartz monzonite and the Copper Belle monzonite porphyry are faults, and none of these three rocks show facies changes that are noticeably related to the contacts. The Turquoise granite is thus known to be of post-Cambrian age and is probably post-Paleozoic, but it is older than the period of thrust faulting that has affected the region, as is shown not only by the faults referred to but also by the flat fault contact beneath the block of Escabrosa limestone resting on it on the south wall of the arroyo that divides Brown's Peak from Gleeson Hill. The relations with the Sugarloaf quartz latite are uncertain, owing to the intense sericitization that both rocks have undergone along their mutual contacts. This indecisive conclusion is disappointing, especially as the granite was interpreted by Wilson as intrusive into the Comanche rocks, but all the contacts seen during this survey were either definitely faulted or ambiguous, and the relations of the granite must be deduced as well as is possible from petrographic work.

PETROGRAPHY

Under most of the area mapped as Turquoise granite lies much-altered rock that is white or light greenish gray to pinkish gray on fresh fracture but stained to tan or red brown along joints. Many specimens show only a few grains of quartz in an otherwise completely sericitized mass; in some of the less altered specimens, crystals of quartz and chalky feldspar up to 3 millimeters in diameter can be identified along with green aggregates of chlorite. The borders of the grains are confused by sericitic material, but the relations of the grains suggest a granitic texture. In some places, owing to the great extent of alteration, whether the rock is granitoid or porphyritic cannot be determined with certainty in hand specimens; accordingly some of the contacts with both the Copper Belle monzonite porphyry and Sugarload quartz latite are indefinite. Part of the differences in mapping between plate 5 of this report and plate 2 in that of Wilson (1927) are due to different interpretations of the admittedly nearly indeterminate rocks.

In thin sections the less altered rocks all show some degree of brecciation and can be seen to have been originally equigranular granitoid and to have ranged from granitic to monzonitic texture, depending on whether the quartz or the microcline was interstitial to all the other minerals. The freshest, or rather the least altered, rocks have saussuritic plagioclase; and most show a highly sericitic core surrounded by relatively clear albite rims. It is impossible to determine the composition of the original plagioclase—presumably it was considerably less albitic than that now found. The plagioclase occurs as subhedral grains in a matrix of microcline and quartz. Chlorite is present and presumably secondary after former biotite. Zoisite and sericite are everywhere common and are even found within the grains of quartz, though naturally most abundantly in the albite. Leucoxene forms pseudomorphs after large crystals of sphene. In some specimens apatite, magnetite or ilmenite, and zircon are accessories, but nearly all apatite shows corrosion, and it is rare in some of the most sericitic rocks. In some of the rocks the quartz exists largely as nests of "lakes" between blocky aggregates of the feldspars. In these, one might suspect that the rocks have been silicified during or after their brecciation and that they might originally have been quartz-poor monzonites. However, because of the advanced alteration of the feldspars, proving this would be difficult even if it were the true history of the rock.

Representative specimens contain about 50 percent saussuritic albite, about 30 percent microcline, and 15 percent quartz, with the rest made up of chlorite and the accessory minerals mentioned. If the quartz is not magmatic the rock probably was originally a monzonite—otherwise, a quartz monzonite. However, in the present altered condition it contains only the minerals specifically implied by the name granite. In order to avoid the multiplication of "monzonites" and any chance of confusion, the rock has been classified on the basis of the present rather than the original composition; the rock is here distinguished as the Turquoise granite.

AGE

Extreme alteration of the Turquoise granite permits only speculations as to original composition. It contains a considerably higher proportion of plagioclase than does the average specimen of Gleeson quartz monzonite, though some variants of the quartz monzonite approach the composition of the Turquoise granite. The two intrusions are on opposite walls of the major thrust fault of the region; and because this fault is known to be large, their original positions were probably several miles apart. To assume that they belong to the same magmatic cycle is not unreasonable, however; for both bodies are almost surely post-Paleozoic and prethrust in age. Although intrusive rocks of post-Bisbee and prethrust age are known in the area, near Fourr Canyon and Ash Creek Ridge, the Turquoise granite does not seem to resemble these as much as it does the Gleeson quartz monzonite. Accordingly, it seems reasonable to assign the Turquoise granite to the same epoch of intrusion as the Gleeson quartz monzonite and the Juniper Flat granite—namely, early Mesozoic. Alteration of the Turquoise granite, however, probably took place after the faulting.

POST-PALEOZOIC–PRE-CRETACEOUS UNCONFORMITY

Between rocks of Paleozoic and Comanche ages in the Bisbee district, Ransome (1904, p. 84, 92) recognized a marked unconformity also found at many places within the area of this report.

The most unequivocal evidences of the discordance are found just east and northeast of Sandy Bob Ranch, on the northwest side of the Mule Mountains. Here the Glance conglomerate, the basal formation of the Bisbee group, rests directly upon the Pinal schist and Juniper Flat granite. Inasmuch as Paleozoic rocks fully 4,000 feet thick are found less than 2 miles to the southwest, apparently great post-Paleozoic erosion occurred prior to the deposition of the Cretaceous rocks. Relations of the Juniper Flat granite to the stratified rocks confirm this. The Juniper Flat granite cuts and metamorphoses all the rocks of Paleozoic age up to and including the Horquilla limestone. The lithology and conformity of the Naco group suggest strongly that the granite is younger than all the rocks of Paleozoic age, and was doubtless formed under at least a moderate cover, in Triassic or Jurassic time. The removal of the overlying rocks and exposure of the granite over the wide areas where it is now seen to underlie the Glance conglomerate must have required a considerable time interval as would reduction of a presumably high structural relief to a much subdued topography. The irregularities in the basal contact of the Bisbee group in the Mule Mountains and the coarseness and irregular distribution of the Glance conglomerate indicate that the topography was not entirely erased. The Glance contains recognizable detritus from the Juniper Flat granite.

Farther north, in Government Draw, a conglomerate composed largely of limestone cobbles and pebbles but with minor amounts of rhyolite rests unconformably on the Colina limestone. This conglomerate is interpreted as the basal conglomerate (Glance equivalent) of the Bisbee formation.

At the south end of the Tombstone Hills, a similar limestone conglomerate, but with few or no igneous constituents, overlies the Epitaph dolomite in approximate structural conformity but on a deeply channeled surface. Pebbles of Abrigo limestone and Bolsa quartzite occur here and testify to the nearby exposure of these formations at the time of deposition of the conglomerate. This conglomerate is also regarded as the basal member of the Bisbee formation which is definitely identified a mile or two to the west. The Bisbee is there deformed similarly to this conglomerate.

In the Tombstone mining area the Comanche rocks rest unconformably on the Epitaph dolomite. The basal conglomerate is discontinuous; but the close folding and numerous faults, together with the scant exposures, make the conformity of the structures of the rocks of Paleozoic and Mesozoic age uncertain.

In the southern part of the Dragoon Mountains, the contacts between Paleozoic and Mesozoic rocks all appear to be faults. However, in Middle Pass, just west of the fork where the trail from the old Gordon's Camp joins the road over the pass, the Comanche rocks rest with apparent depositional contact on the Horquilla limestone. Still farther north, east of Dragoon Peak, just south of the north boundary of the area mapped, the Comanche rests in depositional contact on the Earp formation and nearby upon the Epitaph dolomite. The local structural discordance indicated by these relations is not great, but that it was regionally considerable is shown by the fact that in Fourr Canyon, on the west side of the northern Dragoon Mountains, the Bisbee formation rests at different localities in depositional contact on the Colina limestone, Earp formation, and Horquilla limestone. The basal unconformity cuts across several rather large faults in this area; and despite the complexities due to the later intense deformation and igneous metamorphism, it seems clear that the orogenic disturbance recognized in the Mule Mountains as intervening between the rocks of Paleozoic and Cretaceous ages was likewise active in the northern Dragoon Mountains.

A structural discordance of greater or less magnitude has been recognized between the rocks of Paleozoic and Cretaceous age over a wide area of Arizona (Darton,

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1925, p. 135), New Mexico (Ross, 1925, p. 25–28; Lasky, 1936, p. 21; Paige, 1922, p. 9), and Sonora (Taliaferro, 1933, p. 20–21), but only here, at Bisbee, and in northern Sonora has the discordance been found to be angular and the rocks overlying it to be of Comanche rather than of Colorado age. Accordingly, the orogenic movements here recorded were either local or trends were such as not to have yet been revealed in the parts of the surrounding region thus far studied. Lasky (1938, p. 538–540) pointed out that the remarkable series of deeply cut disconformities and the great thickness of the rocks of Trinity age in the Little Hatchet Mountains, 80 miles to the east in New Mexico, must imply not only rapid sinking of the region but an oscillation of the bordering country. The accumulation of a similar great thickness of rocks of Trinity age in the area of central Cochise County would not, in itself, demand mountainous relief of the bordering land to the north. But in view of the clear evidence from New Mexico (along the same sedimentary basin) and the local evidence of irregularity in the base of this series of Cretaceous rocks, the assumption seems reasonable that here, too, mountainous topography was present in the neighboring country at the time of the incursion of the Comanche sea.

CRETACEOUS SYSTEM

COMPONENTS

The only rocks certainly referable to the Cretaceous system are the Comanche series. A group of volcanic rocks exposed just east of South Pass and in a series of fault slivers along the Dragoon fault to the east, is, however, considered to be probably Cretaceous also. These rocks are entirely bounded by faults, so that their normal stratigraphic relations are only indirectly known. In many respects they resemble the Sugarloaf quartz latite of post-Comanche age and indeed might have been referred to this formation had not similar rocks been recognized by J. R. Cooper [6] in normal succession beneath the Comanche rocks at Walnut Gap in the Dragoon quadrangle to the north. The rocks whose local relations are obscure so closely resemble the volcanic rocks at Walnut Gap that they are here assigned to the Cretaceous. Nevertheless, obstacles to this correlation exist, as will be mentioned, so that the assignment must be regarded as tentative.

CRETACEOUS(?) VOLCANIC ROCKS

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

Volcanic rocks, chiefly andesite and rhyolitic pyroclastic rocks but with some interbedded flow breccias, crop out over an area of roughly 2 square miles in the valley that drains northeastward from South Pass and on the hills to the southeast nearly to the northwest end of Turquoise Ridge. These outcrops are mostly topographically inconspicuous, perhaps in part because the rocks disintegrate readily even when in large blocks but probably more because they are here much faulted and sheared into small masses.

STRUCTURAL RELATIONS

The base on which these volcanic rocks were deposited is nowhere exposed. Generally they dip eastward or northeastward, though locally they are overturned and dip southwestward. They are limited on the west and southwest by the outcrop of the Dragoon thrust; toward the east and northeast they superficially appear to grade into strata that belong almost surely to the Bisbee formation and, indeed, may constitute a lower, conformable member of this formation.

Two obstacles bar the acceptance of this interpretation however. (1) The mudstones of the undoubted Bisbee formation contain much rhyolitic and andesitic pyroclastic material in the region east of the Dragoon Mountains, and some conglomerates of the Bisbee also contain pebbles of andesite and rhyolite; consequently, it would not be surprising to find that massive volcanic rocks locally interfinger with the lower beds of the Bisbee formation. In fact Cooper (written communications, 1947, 1951) has found such rocks at the base of the Bisbee at Walnut Gap just to the north, although not apparently interfingering there with the Bisbee. However, the conglomerates definitely a part of the Bisbee formation in this area are not generally coarse, and pebbles more than 2 or 3 inches in diameter are rare. The conglomerates of the Bisbee, though they contain many pebbles of Pinal schist and representatives of the entire Paleozoic stratigraphic section, also have no pebbles of maroon mudstone like that of the associated Bisbee rocks. The intraformational conglomerates contain mudballs but no pebbles of consolidated rock. On the other hand, the generally coarse conglomerates that interfinger with the volcanic rocks east of South Pass commonly contain boulders a foot or so in diameter. Maroon mudstone strongly resembling that in the Bisbee formation forms abundant pebbles in the conglomerates.

(2) Furthermore, the coarse conglomerates seem to give way abruptly to the finer ones that are more abundant in the undoubted Bisbee formation. In places this boundary is definitely a fault, as in the W½ sec. 11, T. 19 S., R. 24 E., where a wedge of Escabrosa limestone forms a "horse" along it. Although the finer conglomerate abruptly terminates against the coarser in some other places, no fault

[6] Cooper, John R., 1947, oral communication. Cooper regards these volcanic rocks as probably Triassic or Jurassic as they seem unconformable beneath the Bisbee group.

can be provided, for the attitudes are essentially the same in both groups of rocks. However, a study of the relations of the volcanic rocks and associated coarse conglomerates where they abut against the Dragoon fault shows how obscure even a major fault may be when present in a series of vertical beds. The segment of the Dragoon fault that trends east through secs. 14 and 13, T. 19 S., R. 24 E. is accompanied by shingle structure of the adjoining rocks. Slivers of limestone of Paleozoic age are intercalated between layers of conglomerate and volcanic rocks as well as between other slivers of rocks of Paleozic age (only the larger of such slivers can be shown on the scale of plate 5), and all wedge out when followed northwestward. Although thousands of feet, stratigraphically, have been cut out along some of these contacts, hardly one of the fault zones can be traced for more than 100 yards northwestward from the terminus of an individual sliver. Accordingly, the abrupt boundary between the coarse conglomerates that definitely interfinger with the volcanic rocks and the fine conglomerates that clearly belong to the Bisbee formation may represent a large fault, and thus the coarse conglomerates and associated volcanic rocks may be post-Comanche in age, despite the suggestion that they are part of the same series.

Although the local relations are thus not wholly favorable to the interpretation of these rocks as pre-Bisbee in age, the fact that very similar rocks are known to underlie the Bisbee a few miles to the north, that locally the Bisbee contains pebbles that could have been provided by these volcanic rocks, and that the clastic rocks interbedded with these volcanic rocks resemble some of the Bisbee rocks all make it seem reasonable to regard them as Cretaceous; possibly they are Triassic or Jurassic, as suggested by Cooper.

STRATIGRAPHY

Immediately along the Dragoon fault in secs. 10 and 15, T. 19 S., R. 24 E., thin layers of crushed rock largely composed of silicic tuff are common. In the valley northeast of South Pass the tuff gives way to a large mass of hornblende andesite, some of which shows features characteristic of flow breccias. Andesitic clastic rocks are associated here, but the attitude of the series is difficult to determine. The dips appear to be mostly northward or eastward. To the east is more siliceous tuff, called "rhyolite tuff" in the field. This intimately interfingers with coarse limestone conglomerate that contains pebbles of Gleeson quartz monzonite, Bolsa quartzite, and maroon mudstone that may have been derived from the Bisbee formation. Some andesite is also found but is subordinate near and east of Barrett Camp. From this locality eastward considerable sandstone, grit, and mudstone intercalates with the tuff, and the section, except for the volcanic rocks, is almost to quite indistinguishable from the definite Bisbee formation to the north.

PETROGRAPHY

Quartz keratophyre tuffs are the dominant siliceous volcanic rocks of this area. These fine-grained reddish or gray rocks show some fragmental structures in hand specimens, where the only minerals recognizable are quartz, in rounded phenocrysts; chalky feldspar; and in some rocks, chlorite that is pseudomorphic after biotite.

Under the microscope the quartz shows the forms of rounded bipyramids. The only feldspar present as phenycrysts is albite, crowded with alteration products that testify to an originally more calcic composition. Chlorite occurs in some specimens, but in many no dark minerals other than magnetite are recognizable. Some specimens show a few minute grains of orthoclase, but in many none is recognizable, because the groundmass is cryptocrystalline. Shard structures are common but not invariably present. Included fragments of fluidal andesite are abundant. The surficial origin of most of the rocks cannot be doubted, though the associated felsite dikes resemble some of them greatly in hand specimens. The granophyric textures of the dikes as seen under the microscope serve to distinguish them clearly.

The sparseness of the potash feldspar recognizable in the rock, the high albite content of the feldspar, and the primary quartz render the name quartz keratophyre appropriate for the rocks in their present condition. However, there is a distinct probability that, as formed, the rocks were dacites, or more likely (from the residual clues of former biotite), quartz latite. The lavas strongly resemble some of the altered facies of the Sugarloaf quartz latite; and as their outcrops extend practically to the area of Sugarloaf quartz latite, they may really be part of that formation, though this is not considered as likely as the interpretation here adopted.

The andesites of this area are pinkish-gray rocks that weather reddish brown. They contain local conspicuous phenocrysts of hornblende that are dark brown from oxide rims, though in some hornblendic specimens the amphibole is so thoroughly resorbed as not to be certainly identified with the hand lens. Feldspar forms much smaller phenocrysts, 0.5 to 1.0 millimeter in length, but is recognizable in all specimens examined. The groundmass is aphanitic. Thin sections show that altered hornblende and plagioclase are the only phenocrysts. The hornblende, like that in the S O volcanics, is highly oxidized and in some specimens is represented only by rims of hematite or magnetite that outline the form of the preexistent mineral. In all the specimens examined, the high sericitization of the plagioclase prohibited estimation of the original composition. No pyroxene could be identified nor were there any signs of its former presence. Sericite, calcite, and epidote are abundant in the rocks studied, along with a little chlorite and the primary accessories magnetite and apatite. The texture is pilotaxitic. The rocks are altered hornblende andesites.

COMPARISON WITH OTHER VOLCANIC FORMATIONS

The primary composition of these rocks can only be inferred within wide limits. Owing to the lack of identifiable fossils, however, it seems important that the bases for the recognition of the several volcanic series should be presented. Especially is this true because their mutual stratigraphic relations are largely obscure matters of inference.

It seems clear that the volcanic rocks east of South Pass are not closely related to the S O volcanics. The andesites of the S O volcanics are hornblendic, and the hornblende has undergone alteration very similar to that shown by these rocks, but in the S O volcanics practically no phenocrysts of plagioclase have been found. Furthermore, most of the siliceous rocks of the S O volcanics contain phenocrysts of sanidine, which is absent from these rocks.

Similarly, these rocks differ from the Pearce volcanics in several respects. Both hornblende and plagioclase are present as phenocrysts in both groups of andesitic rocks, but the Pearce volcanics show augite as phenocrysts in nearly all specimens. The plagioclase of these rocks has been so altered that its composition cannot be compared with that of the plagioclase in the Pearce volcanics. The siliceous rocks of the Pearce volcanics all contain sanidine as conspicuous phenocrysts, along with quartz, whereas in the siliceous rocks east of South Pass, the only phenocrysts other than quartz are of plagioclase.

These rocks resemble the Sugarloaf quartz latite much more closely. Both formations contain quartzose lavas with phenocrysts of quartz, plagioclase, and altered biotite, and the groundmasses are similar. Locally the Sugarloaf quartz latite contains sanidine phenocrysts as well, but in many large areas of the formation these are not found. The siliceous rocks are very similar; however, no andesites have been found in such intimate association with the Sugarloaf quartz latite as these rocks east of South Pass, unless the rocks in the northernmost of the Courtland Hills are to be so classed. The two northernmost of the Courtland Hills contain lavas that are far less altered than those of the main part of the mining area and thus appear distinctly different in the field. However, the petrographic similarities between the siliceous rocks of these northern hills and the Sugarloaf quartz latite are very close, and the principal difference between the two groups is the abundance of andesite in the northern hills and its absence from the Sugarloaf, as recognized farther south. The alteration of both the main exposed parts of the Sugarloaf quartz latite and the rocks east of South Pass prevents confident correlation with the much less altered rocks of the northernmost Courtland Hills; but if such correlation were made, it would reconcile the disappearance of the Sugarloaf quartz latite toward the north just where it joins these rocks, which differ only in their intimate assocation with andesite. Both are similarly related to the Dragoon fault. The Sugarloaf, however, rests on Bisbee rocks, whereas these either are more likely pre-Bisbee or interfinger with the basal beds of that formation.

COMANCHE SERIES

BISBEE GROUP AND BISBEE FORMATION

The name Bisbee beds was applied by Dumble (1902, p. 696–715) to the Cretaceous rocks of the Mule Mountains. Ransome (1904, p. 56) referred these rocks to the Bisbee group in which he recognized four formations: the Glance conglomerate at the base, followed by the Morita formation, the Mural limestone, and the Cintura formation at the top. These subdivisions are readily recognized in the Mule Mountains. However, as described in detail in the discussion of the Mural limestone, the Mural limestone wedges out rapidly toward the north and has not been recognized north of the Mule Mountains. Accordingly, in more northerly parts of the area it is not feasible to distinguish the Morita and Cintura formations, which resemble each other closely and have yielded very few fossils, none diagnostic. Thus, except forthe Glance conglomerate, which is very irregularly distributed, the Cretaceous rocks in the Tombstone Hills and Dragoon Mountains have few characterizing features usable for mapping subdivisions, and the name Bisbee formation is here applied to them. This map unit thus includes the northerly representatives of the Comanche rocks, without commitment as to what part of the type section at Bisbee is represented. In view of the scarcity of diagnostic fossils, the beds here called the Bisbee formation may possibly represent rocks in part younger than the type Bisbee group; but their lithologic resemblance to the Morita and Cintura is such as to furnish good ground for using the name, especially as the top of the Cintura as recognized in the Mule Mountains is merely erosional. In the Dragoon Mountains a limestone conglomerate common near the base of the Bisbee formation is regarded as equivalent to the Glance conglomerate and referred to as the

Glance conglomerate member of the Bisbee formation. It is not, however, distinguished on the map from the rest of the Bisbee formation.

GLANCE CONGLOMERATE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Glance conglomerate is exposed as a narrow band at the base of the Bisbee group in the hills east of Sandy Bob Ranch. Two small patches near the head of the west fork of Sandy Bob Canyon occupy deep gulches carved in the surface of the Juniper Flat granite, but on either side the Morita overlaps the conglomerate and rests directly on the granite. Small patches of conglomerate are also found just north of Government Draw and scattered in the south part of the Tombstone Hills. These bodies of conglomerate are regarded as basal Comanche but are not distinguished as Glance conglomerate on plate 5 but are simply referred to the Bisbee formation.

East of Sugarloaf Hill, near Gleeson, about 10 miles from the most northeasterly of these outcrops, are some small exposures of conglomerate made up largely of rounded pebbles and cobbles of limestone. Similar rocks found in sporadic outcrops at least as far north as the edge of the map area are all considered as the Glance conglomerate member of the Bisbee formation and described with that formation.

The fairly resistant Glance conglomerate tends to form ledges at the base of the overlying Morita. The prominence of these ledges is conditioned both by the immediately underlying rock and by the relative altitude of the outcrops above the valley floors. Where the Pinal schist is the basement rock, the ledge of Glance conglomerate is conspicuous; but where the Juniper Flat granite or one of the formations of the Naco group lies below, the ledge is subdued.

STRATIGRAPHY

Wherever seen the base of the Glance conglomerate is an erosional unconformity. Ordinarily the local relief of this surface is not very great, but it is as much as 50 feet in 200 feet of strike distance on the west side of Epitaph Gulch and over 100 feet in less than 500 feet near the head of the west fork of Sandy Bob Canyon. In the Bisbee area Ransome (1904, p. 57) reports a broad area over which the irregularities of this surface are small, but south of Mule Gulch he recognized that the conglomerate filled hollows in a buried topography with relief comparable to that of the present day. Generally these vagaries appear to be representative of most of the area here considered.

The Glance conglomerate ranges widely both in thickness and lithology. The section exposed east of Sandy Bob Ranch typifies the formation where overlying Pinal schist. Here the Glance is made up largely of angular or poorly rounded fragments of schist and granite porphyry with subordinate amounts of limestone. The pebbles average 2 or 3 inches in diameter but attain a maximum of about a foot. About 6½ feet below the top is a local lens of conglomeratic limestone, overlain by coarse conglomerate (2-inch pebbles) which becomes fine-grained mudstone a few inches thick. Another thin bed of conglomerate that passes upward into the basal shale and sandstone of the Morita forms the top. The upper contact appears to be gradational, and the Glance to be merely the basal conglomerate of the Bisbee group.

Where the Glance rests on limestone or dolomite, the conglomerate commonly contains a great many limestone and dolomite pebbles. These ordinarily are coarse and reach cobble or even boulder size. They are generally better rounded than the subordinate accompanying pebbles of quartzite or igneous rocks. Upward they give way through a thin transition zone to the finer clastic rocks of the Morita.

THICKNESS

The Glance varies rapidly in thickness, owing to the irregularities in the surface of unconformity beneath. In the section east of Sandy Bob Ranch a thickness of about 50 feet wedges out completely in about 1,000 feet along the outcrop. Just across the ridge to the east, in the head of the west fork of Sandy Bob Canyon, the variations are even more abrupt: the conglomerate fills an old valley to depths of over 100 feet and wedges out laterally within less than 500 feet. Tenney (1935, p. 225) states that the Glance conglomerate at Bisbee ranges from 25 to several thousand feet in thickness.

CONDITIONS OF DEPOSITION

No fossils, other than transported, have been found in the Glance conglomerate. However, the gradational contact with the overlying Morita formation suggests the marginal deposit of an encroaching sea. Thus it is probably in part a terrestrial flood plain or alluvial conglomerate but in part may be marine. At Tombstone, in particular, the close association with the overlying fossiliferous limy rocks suggests a marine origin.

MORITA FORMATION

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

Within the area here described, the Morita formation has only been recognized in the Mule Mountains. Rocks perhaps correlative occur widely to the northwest and northeast but in absence of a recognizable Mural limestone cannot be discriminated as a formation from overlying rocks that may be correlative with the Cintura. The Morita underlies most of the north part of the Mule Mountains where its outcrops cover nearly 40 square miles.

Its characteristic sandstones, alternating with less resistant shales and combined with generally low dips, find expression in a mesa and bench topography.

STRATIGRAPHY

The basal beds of the Morita are gradational to the underlying Glance conglomerate. In mapping, the contact was placed at the lowest mudstone bed thick enough to be topographically marked.

The Morita in general consists of a series of alternating sandstones and mudstones or shales. Many of the sandstones are persistent and form ledges traceable for thousands of feet, but some are abruptly lenticular, as is clear in the beds just below the Mural limestone on the north side of Mule Gulch in the Bisbee district. Many have scour and fill structures at the base; many are current bedded. The sandstones are commonly cemented by lime but locally are quartzitic. The mudstones and shales are generally brown or maroon, and wash from them stains the sandstones, which are naturally gray.

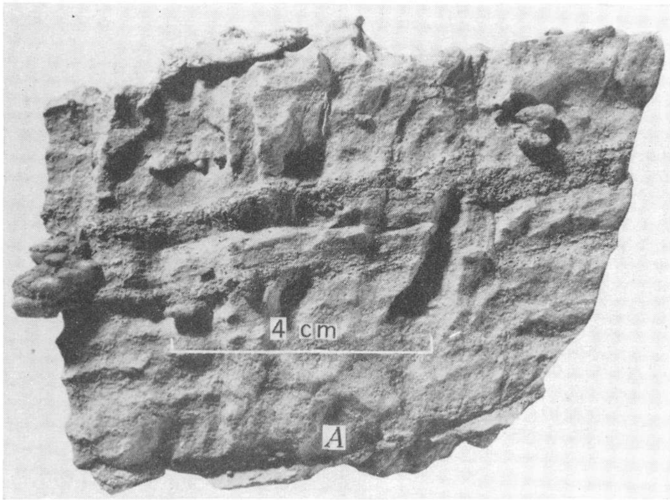
A partial section of the Morita measured by tape and clinometer in the escarpment east of Sandy Bob Ranch appears to be representative of the formation and is here given for this reason.

Partial section of Morita formation east of Sandy Bob Ranch

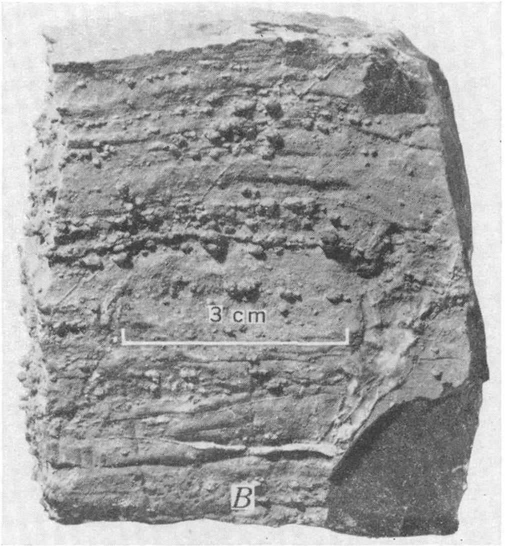
[Measured by James Gilluly and Edgar Bowles]

	Feet
Top of section:	
Erosion surface with many hundred feet of overlying beds removed.	
1. Quartzite, conglomeratic at base with limestone pebbles; a thin shale parting about 5 feet above base; many worm borings; forms strong ledge	24
2. Mudstone, maroon, 6-inch limestone bed and subordinate thin red sandstones; forms slope	66½
3. Sandstone, gray, crossbedded; two shaly sandstone partings, one 8 feet, the other 18 feet above base	30
4. Mudstone and sandstone, maroon, dominantly mudstone above, sandstone below, a zone of limy concretions in the mudstone	76
5. Sandstone, quartzitic, gray, massive; forms cliff	7
6. Sandstone, poorly consolidated, red-brown, passes gradationally upward into blocky mudstone	34
7. Sandstone, massive, crossbedded, carries many shale and some limestone fragments	20
8. Shale and shaly sandstone, maroon; poorly exposed and forms slope	35½
9. Sandstone, conglomeratic, with especially conglomeratic zone at base; crossbedded; contains shale pellets; forms very prominent and persistent ledge	30
10. Sandstone, poorly consolidated, reddish-brown	16½
11. Sandstone, gray, flaggy, locally crossbedded, coarse-grained; forms subordinate ledge	9
Top of Section—Continued	
12. Concealed, probably chiefly red-brown sandstone and mudstone	27
13. Sandstone, ranges from fine sandstone to fine grit, thick-bedded, partly flaggy, partly cross-bedded; contains shale pellets locally and a 2-foot bed of limestone conglomerate about 15 feet above base; forms prominent ledge	45
14. Sandstone, silty, to sandy mudstone, chocolate-red; forms slope	38
15. Sandstone, light-gray, massive, in three beds	10
16. Sandstone, silty, interbedded with subordinate sandy mudstone and a few thin beds of well-sorted sandstone; more silty than lower members	51
17. Sandstone, quartzitic, gray, slightly reddish tinge on fresh fracture, crossbedded, very lenticular, thickens to 17 feet within 100 feet along strike	2½
18. Mudstone, sandy, interbedded with silty sandstone, red-brown, a few thin beds of well-sorted sandstone; coarse sandstone with many shale pebbles toward top; forms slope	46
19. Sandstone, gray, massive beds up to 4 feet thick, well sorted as to grain size but arkosic, micaceous, with carbonaceous material; forms persistent ledge	13
20. Largely concealed, probably chiefly muddy sandstone with a few thin ledges of better sorted sandstone, becomes more muddy upward; red-brown forms slope	50
21. Sandstone, gray; average grain size about 1 millimeter; lime-cemented, animal trails on top surface; forms ledge	4
22. Sandstone, muddy, poorly exposed; forms slope	20
23. Sandstone, crossbedded, in layers 2½–9 inches thick; worm borings conspicuous; average grain about 1 millimeter; forms ledge	8
24. Shale and sandstone, poorly exposed in slope	10½
25. Sandstone, reddish-gray, weathers brown; lime cement; many worm trails; forms ledge	3½
26. Sandstone, shaly at base, passes upward into sandy shale; chocolate-red; forms slope	13
27. Sandstone, massive, lime-cemented; fine-grained, somewhat concretionary; forms ledge	4
28. Shale and sandstone, weakly cemented, some nodular limestone masses, probably concretionary; forms slope	22
Total	715
Gradational contact.	
Glance conglomerate:	
Conglomerate, coarse at base but grading up into fine sand at top. Top member (6 feet thick) of conglomerate which locally aggregates 52 feet thick and rests on Pinal schist.	

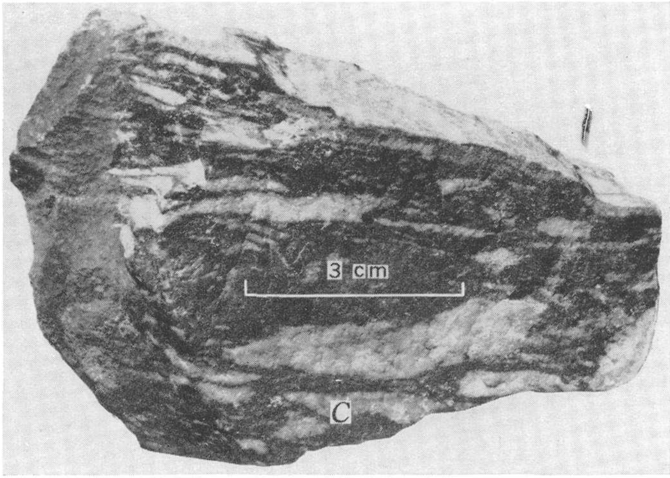
The section described here, though only a small part of the formation, is representative of most of the Morita in the Mule Mountains. Toward the top the Morita varies somewhat and includes, in its upper 500 feet, sporadic beds of oyster-bearing limestone, each 5 to 8 feet thick. Three such limestone beds have been found on the divide between Abbot and Johnson Canyons on



A. SPECIMEN FROM THE EPITAPH DOLOMITE
Shows nodular chert bodies in sandy gray dolomite.

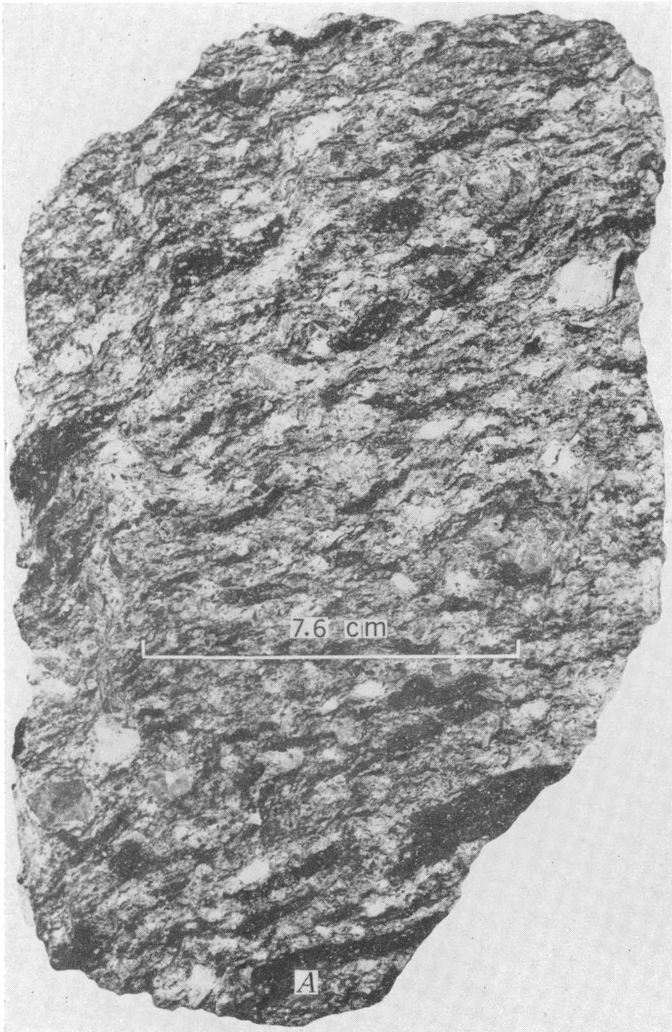


B. SPECIMEN FROM THE EPITAPH DOLOMITE
Shows silica nodules arranged nearly parallel to bedding in a dark-red dolomite that weathers light reddish tan.



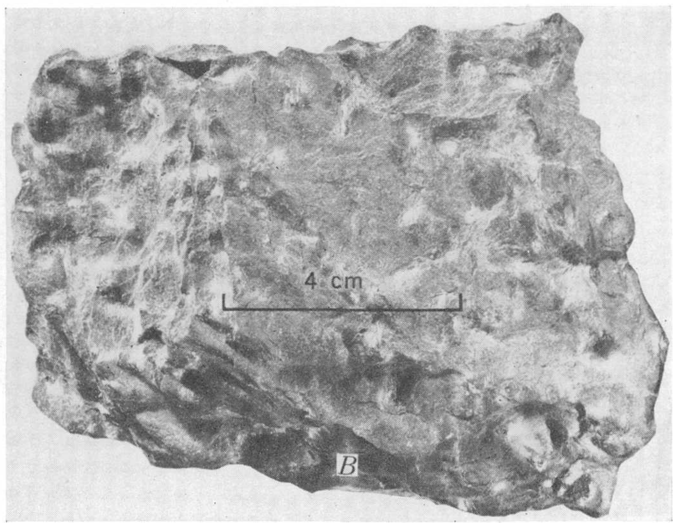
C. CONGLOMERATE FROM THE BISBEE FORMATION
Limestone conglomerate strongly sheared; from thrust zone north of Mount Glen.

REPRESENTATIVE HAND SPECIMENS FROM THE EPITAPH DOLOMITE AND THE BISBEE FORMATION



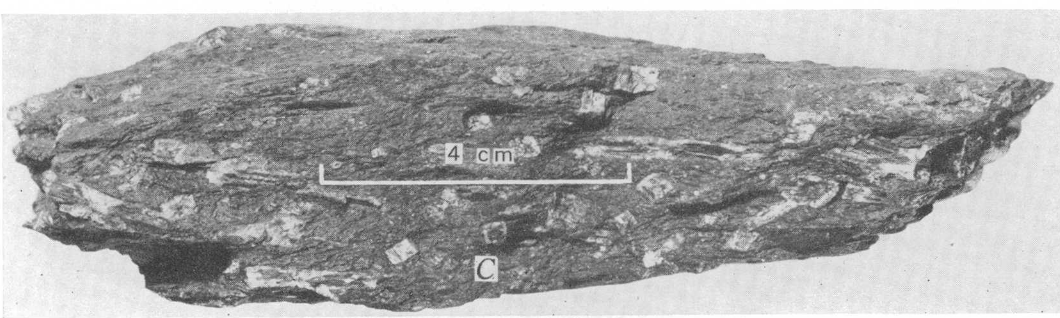
A. WELDED TUFF FROM THE S O VOLCANICS

Welded tuff, containing fragments of black scoria, light-gray glass, with a little chert and limestone. From south slope of Stockton Hill.



B. PHYLLITE FROM THE BISBEE FORMATION(?)

Knotted zoisite phyllite from north of Fourr Ranch.



C. SCHIST FROM THE BISBEE FORMATION(?)

Graphitic chiastolite schist from north of Fourr Ranch.

REPRESENTATIVE HAND SPECIMENS FROM THE S O VOLCANICS AND THE BISBEE FORMATION(?)

the east flank of the Mule Mountains. From the lowest (about 500 feet below the base of the Mural limestone), a considerable fauna (USNM 17476) was collected; the upper beds, though abundantly fossiliferous, furnished no identifiable material other than *Ostrea* fragments.

There appears to be no abrupt contact with the overlying Mural limestone; the limestone members become more abundant, and the finer clastic rocks become well-laminated greenish shale rather than chocolate-colored mudstone, but the transition appears to be due to interfingering. The sandstone beds of the lower part of the Mural are apparently identical in mineralogy and grain size with those of this formation. A similar impression of transition was received by both Ransome (1904, p. 65) and Stoyanow (1949, p. 25) although Stoyanow has restricted the Mural limestone of Ransome to the massive upper beds of the formation as originally defined, separating the fossiliferous thinner bedded strata beneath as a new formation, the Lowell.

Stoyanow's (1949, p. 23–26, pl. 5) description of the section on Mural Hill, near Bisbee indicates that he also included beds mapped as Morita by Ransome in his Lowell formation. Although he gives thicknesses of only part of the beds and does not indicate either in map or discussion where he places the lower boundary of his Lowell formation, he evidently places it far below the "3d escarpment" which is at least 100 feet stratigraphically below the base of the Mural as mapped by Ransome. Stoyanow's map shows the beds here to be dipping vertically, whereas Ransome's map shows dips of 20°. Presumably Stoyanow's "map" is to be taken as a diagram of the points of intersection of the beds in a traverse up the spur rather than as a geologic map.

THICKNESS

In the Bisbee area to the south, Ransome (1904, p. 64) reported the Morita formation to be 1,800 feet thick. A rough measurement 2 miles north of the Bisbee quadrangle boundary gives about 3,000 feet. The formation thickens rapidly to the south of the Bisbee district (Ransome, 1904, p. 64; Stoyanow, A. A., oral communication, 1937), and into Sonora. North of the Mule Mountains, which contain, in Abbot Canyon, the most northerly exposure of the Mural limestone, exist considerable thicknesses of strata lithologically closely comparable to the Morita, but these rocks may in part correlate with the essentially identical Cintura—they are here mapped as Bisbee formation.

CONDITIONS OF DEPOSITION

The sporadic limestone members of the Morita were obviously formed under marine conditions, an inference that is strengthened by the interfingering at the top with the Mural limestone. The red-brown mudstones, the local channel sandstones, and the general paucity of fossils, on the other hand, might be thought to connote continental conditions—as might the abundant petrified logs in it. Furthermore, the Bisbee formation in the Tombstone Hills has yielded fresh-water faunules from closely similar rocks. The Morita was possibly laid down under estuarine conditions that fluctuated between marine, brackish, and fresh water. Toward the south the marine part extends lower in the section (Stoyanow, 1949, pp. 6–13, 23–27), and toward the north and west the brackish and fresh-water environment seems to have been more persistent. We probably have to do here with marginal deposits in an estuary of the Comanche sea—the land lay not far away to the west or northwest. The lenticular form and crossbedding of the sandstones suggest that the water was generally shallow at the time the Morita was laid down, and doubtlessly sinking and sedimentation were about equally rapid.

MURAL LIMESTONE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Mural limestone extends in a strip about 1,000 feet wide along the eastern side of the Mule Mountains from Abbot Canyon, where it disappears beneath the alluvium of the Sulphur Spring Valley, to the south edge of the quadrangle. In the Bisbee quadrangle to the south it is widely exposed.

The lower part of the formation, constituting roughly half of it, is relatively weakly resistant to erosion, as compared with either the sandy Morita below or the massive limestone above. This lower member thus produces a notable topographic sag that is emphasized by the remarkable cliffs and walls carved in the overlying massive limestone member—walls so precipitous and continuous as to make the name Mural highly appropriate for the formation. The overlying cliff-forming member generally constitutes about one-third of the formation; the rocks above it are less massive and are carved into more rounded slopes, though they are generally bolder than those of the overlying Cintura formation.

STRATIGRAPHY

The Mural limestone is composed of three readily distinguishable members: a lower part, generally making up somewhat more than half of the formation, composed of relatively thin-bedded limestone interbedded with preponderant shale and sandstone; the intermediate member composed of massive limestone with practically no clastic material; an upper member with thinner beds ranging from shale and sandstone to mudstone and limestone.

The base of the Mural limestone is arbitrarily placed, following Ransome, at the top of the highest thick resistant sandstone or quartzite beneath a consistently limy series of beds. The contact so mapped certainly transgresses chronological lines, for sandstone and limestone at this part of the section interfinger everywhere, and the formation as a whole (and each of its major members) thins notably toward the north.

The lower member of the Mural limestone ranges in thickness from about 600 feet in Mule Gulch east of Bisbee to about 335 feet in Abbot Canyon. The beds differ abruptly along the strike, both in lithology and thickness, and different kinds of rock alternate rapidly at any given place—yet the lithologic variety that permits confident recognition of the member wherever it occurs is generally consistent. Most of the member consists of rather soft shaly and limy sandstone, generally greenish gray and weathering buff, with a considerable proportion of shaly and sandy dark-blue-gray limestone and green and black shale. Many of the sandstone members are massive, but the limestone and shale are both in beds that are only locally as much as 3 feet thick. Fossils are abundant, and, in contrast to those of the overlying massive member, are readily collected, because they tend to loosen from their matrix on weathering.

The lower member of the Mural ranges greatly in thickness within short distances—largely by lensing of individual beds. For example, of two carefully measured sections only 1,000 feet apart along the strike, short distances north of Highway 80 in Mule Gulch (Bisbee quadrangle), the thicknesses are respectively about 400 and 600 feet. No structural disturbance is apparent here, and many of the beds can be seen to cut out in a way that must be accounted for by deposition and erosion on the sea floor rather than by angular unconformity or faulting. It is also notable that of these two sections, the more northerly is the thicker, yet the regional thinning of the lower Mural as well as of the formation as a whole, is in the opposite direction. (See fig. 4.) The lower member is 1,104 feet thick at the international boundary east of Naco, where it has been distinguished as the Lowell formation by Stoyanow (1949, p. 12), but is only 335 feet thick at Abbot Canyon, the most northerly exposure at which it can be recognized. The member has been distinguished on plate 5.

Immediately overlying the lower member in most places, but at some points separated from it by thinner limestones, is the massive limestone of the Mural that makes the formation so prominent a feature in the landscape. This light-blue-gray limestone weathers pale gray or white. The massive bed ranges from 75 to about 240 feet in thickness and in many exposures shows only a few faint traces of bedding. The cliff formed by this bed is so steep that in places one must skirt along it for several hundred yards in order to traverse it. Fossils, many of the "reef" facies, are abundant but difficult to collect. *Orbitolina texana* and species of *Ostrea*, *Lunatia*, and *Caprina* are most common.

Above this massive limestone are thinner bedded limestones, generally 6 to 10 feet thick, that otherwise resemble it. They range from 20 to about 140 feet in aggregate thickness.

In some of the more northerly exposures, the most prominent reef of the formation is relatively higher than toward the south and underlain, rather than overlain, by thinner (6–10 feet) beds of limestone free from shale or sandstone interbeds.

The upper contact of the Mural, as well as the lower, is arbitrary: transition to the overlying Cintura formation is evident. Coarser clastic rocks are interbedded with the limestone members at intervals that become closer upward. The contact was placed in mapping at the base of the first thick sandstone of the dominantly clastic strata. A few limestone beds several scores of feet higher contain fossils like those of the Mural, but they are much subordinate to the sandstone and mudstone in the Cintura.

The series of partial sections of the Mural limestone shown in figure 4 illustrates the variation in lithology and notable northward thinning. The Mural in this longitude probably never extended more than a few miles farther north than present exposures in Abbot Canyon.

THICKNESS

Ransome (1904, p. 67) reported the Mural limestone in the Bisbee area to be about 650 feet thick. This thickness was doubtless measured in the northern part of the Bisbee quadrangle: two sections measured during this survey just north of highway 80 in Mule Canyon gave 500 and 700 feet, respectively, for the thicknesses to the top of the massive "reef member," and the lower part of the Mural thickens rapidly to the south to more than 1,100 feet at the international boundary east of Naco (Stoyanow, 1949). Apparently lower stages are represented by fossils along the boundary than toward the north: the thick lower Mural strata with a rich ammonite fauna apparently represent equivalents of part of the nonfossiliferous Morita of more northerly areas. (See Cretaceous fossils.) Northward toward the area of this map, the Mural continues to thin. At Dixie Canyon, just south of the quadrangle boundary, the massive limestone member is only 230 feet thick. In Abbot Canyon the entire formation is only 517 feet thick, and the massive limestone member has thinned to 177 feet as well as having an 8-foot bed of quartzite

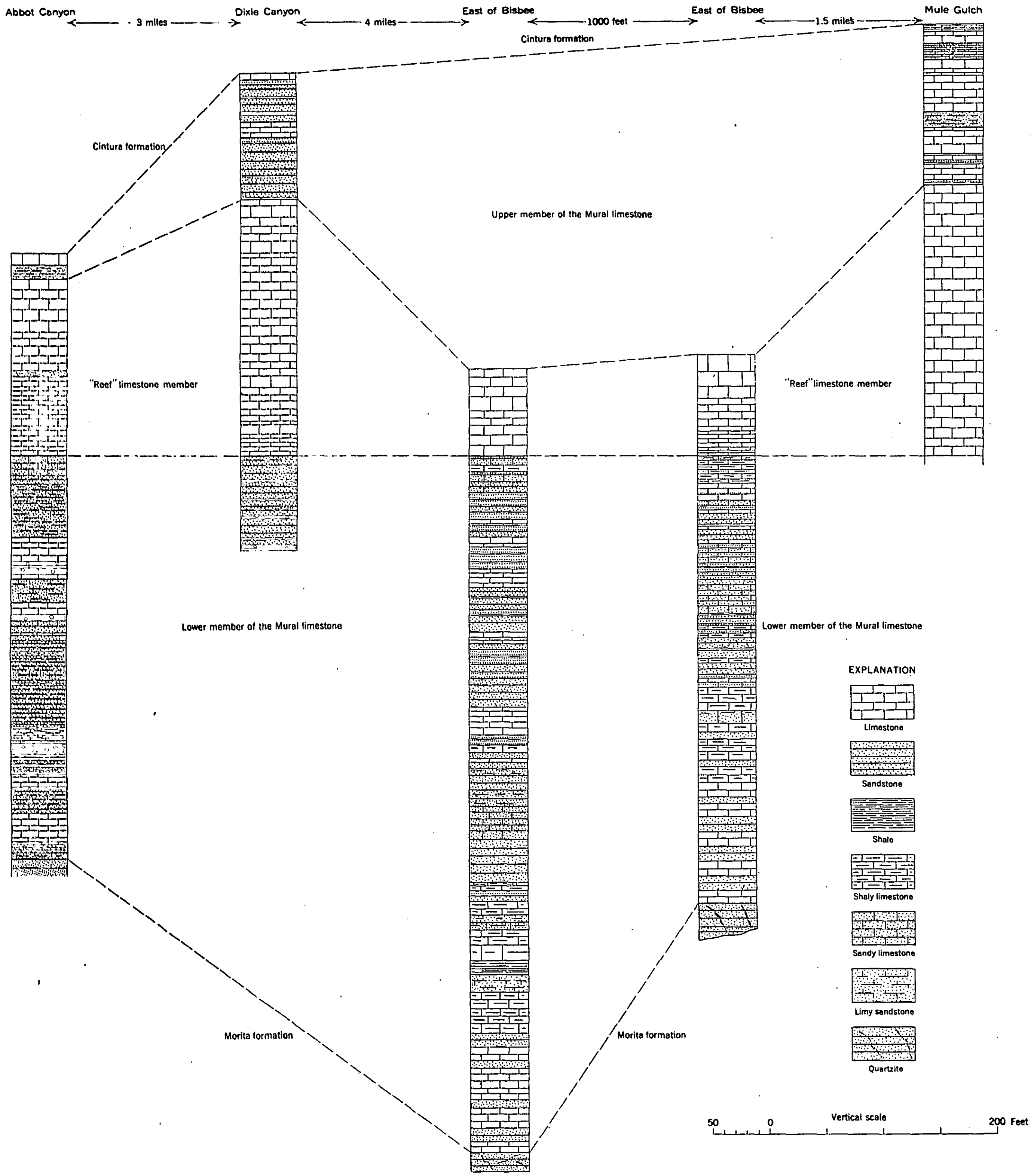


FIGURE 4.—Correlation of the Mural limestone in the Bisbee and Pearce quadrangles.

intercalated near the middle. If the rate of thinning shown by these sections continues to the north under the alluvium of Sulphur Spring Valley, the formation must wedge out completely in another 4 or 5 miles. Thus the thick clastic section of the Tombstone Hills and Dragoon Mountains may contain age equivalents of the Mural, but represented by nonfossiliferous clastic facies. The few thin limestone members intercalated in these northern localities may represent either an attenuated representative of the Mural limestone or analogous tongues of like lithology: the few fossils yielded by these northern beds are not diagnostic but are compatible with an age equivalent with the Mural. These probabilities are expressed by applying the name Bisbee formation to the northern series.

Figure 4 illustrates the variations in the Mural limestone in the Mule Mountains.

CONDITIONS OF DEPOSITION

The clastic components of the lower Mural and their lenticularity and current bedding indicate that this part of the formation was deposited in relatively shallow water. The more massive upper part contains fossils suggesting a reef facies (Reeside, J. B., Jr., oral communication, 1937 and is probably also of shallow marine origin. The relations to the Morita and Cintura formations suggest that the persistence of the estuarine or coastal plain environment represented by them was interrupted by an incursion of more open marine conditions. Possibly the seaway was opened by greater subsidence at this time, though the aspect of the fauna does not permit a great depth of water to be assumed. It is perhaps more likely that a change in the configuration of the bordering lands led to a temporary lessening of the clastic detritus locally available. The remarkable oscillations of the land recorded in rocks of about the same age in the Little Hatchet Mountains of New Mexico, about 75 miles to the east (Lasky, 1938, p. 538–540) perhaps offer support to this idea.

CINTURA FORMATION

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Cintura formation, the top constituent of the Bisbee group as recognized by Ransome in the Bisbee quadrangle, occupies less than 2 square miles of the area included in this survey. It forms the eastern slopes of the Mule Mountains just north of the Bisbee quadrangle and west of Stevenson Ranch. The topography cut on this formation is one of ledges and slopes and, though somewhat rugged, is not nearly as conspicuous as that on the adjacent Mural limestone.

STRATIGRAPHY

The base of the Cintura formation is an arbitrary one, for a complete transition exists between it and the underlying Mural limestone. Above the massive member of the Mural limestone, clastic members are intercalated between the dominantly limy beds. Upward, these clastic beds become more abundant and sandy, rather than shaly; and within a few tens of feet essentially all the beds are clastic. The first thick sandstone in this transitional series has been selected as the base of the Cintura formation. In most sections a few thin limestones can be found above this sandstone, the uppermost as much as 200 feet stratigraphically higher. These limestone beds appear much like those in the Mural and contain oysters.

The main part of the Cintura formation, practically identical lithologically with the Morita formation, consists of a series of alternating mudstone and sandstone beds—the mudstones, maroon or green, rarely gray; and the sandstones, buff to gray. Many of the sandstones are prominently crossbedded and gritty.

THICKNESS

Although at least 1,800 feet of beds have been assigned to the Cintura formation in the Bisbee quadrangle (Ransome, 1904, p. 68–69), only a few hundred feet of the basal part of the formation are represented in the area of this survey, as the upper beds have been removed by erosion.

CONDITIONS OF DEPOSITION

The essential similarity between the Cintura and Morita formations implies a return to the same conditions as led to the deposition of the Morita. Presumably these were estuarine, with the interbedded fossiliferous limestone beds giving testimony that during at least part of the time the environment was marine.

BISBEE FORMATION

NAME

The rocks of the Bisbee group, as recognized by Ransome in the Bisbee quadrangle, are there divisible into formations as described in the preceding sections. North of the Mule Mountains, however, no lithologic equivalent of the Mural limestone occurs, and the group is there divisible only into a conglomeratic facies of irregular distribution and a finer clastic facies of great thickness. It seems best to recognize the northern rocks as constituting a map unit, the Bisbee formation, rather than to attempt to correlate them in more detail with the type section at Bisbee. As thus defined, the Bisbee formation is the most widespread of the pre-

Pliocene rocks of the area. If the suggestion made by Stoyanow (1949, p. 30) that the beds at Tombstone are all younger than Mural "and possibly even post-Cintura" is correct, the designation as Bisbee formation would still seem appropriate in view of the definite Comanche age of these rocks, even though their exact placement within that series is unknown. As noted by Reeside, however, although the fossils of the "Blue limestone" at Tombstone are not precisely identifiable, they resemble those of the Mural closely. The same is true of fossils collected several thousand feet above the base of the Bisbee east of the Dragoon Mountains. Accordingly, the Bisbee formation as here recognized probably includes equivalents of Morita, Mural, Cintura, and possibly much younger Comanche strata to the south.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Bisbee formation is well exposed in the Tombstone Hills, in the pediment extending from them to the hills at Charleston, and in the low hills that protrude from the valley fill along the San Pedro River between Boquillas and Lewis Springs. There are also many small outcrops of the Bisbee in the Courtland and Gleeson areas and a few along Government Draw. The low hills bounding the main Dragoon Mountains on the northeast between North Courtland and Middlemarch Canyon are chiefly made up of the Bisbee formation, and large bodies occur in the main ridge itself between Walnut Springs and Soren's Camp. In the north part of the map area, the Bisbee formation is the major formation exposed in the main ridge between Fourr Canyon on the west, the mouth of Cochise Stronghold on the east, and the map boundary on the north. Small exposures also exist in Ash Creek Ridge and the low hills nearby, east of Pearce. In the area of intense thermal alteration that extends from about the latitude of Middle Pass almost to the north end of the area, considerable difficulty is common in distinguishing the the Bisbee formation from the Pinal schist. Thus some areas mapped as Pinal possibly should be included in the Bisbee, notably the mass that extends north-northwest from China Peak as a reentrant in the boundary of the Stronghold granite. In Fourr Canyon, possibly some of the rocks included in the Bisbee also should have been assigned to the Pinal, but this is less probable. In general, sufficient persistent distinguishing characters of the two formations are present to make the assignment of any large body of rock to one or the other satisfactory even where the metamorphism has been intense.

Generally the Bisbee formation is not prominent in the topography except where altered to hornfels. Elsewhere the alternating sandstone and mudstone beds of which it is mainly composed weather to gentle interrupted slopes and are clearly much less resistant to erosion than most of the calcareous rocks of Paleozoic age. Both in the Tombstone Hills and the foothills of the Dragoon Mountains northeast of South Pass, intrusive rocks sustain the prominent topographic eminences, and the Bisbee formation forms hills only where such intrusions are found. However, in the areas of thermal alteration, the formation is very much more resistant and forms prominent ridges and peaks.

STRATIGRAPHY

The base of the Bisbee formation is exposed in only a few places, but wherever seen, it is a surface of unconformity. In the Tombstone Hills this unconformity is chiefly erosional, and only by noting the varying stratigraphic horizons of the Naco group at the contact can a pre-Bisbee structural disturbance be locally established. (See p. 67.) In Epitaph Gulch the basal beds of the Bisbee are composed of conglomerate that contains pebbles and cobbles, up to 8 inches in diameter, of recognizable rocks derived from the Abrigo, Bolsa, Escabrosa, and formations of the Naco group. The conglomerate rests in essentially parallel attitude on the Epitaph dolomite, but the contact is deeply channeled (as much as 50 feet within a strike distance of 200 feet) into the underlying dolomite. Elsewhere the contact is also irregular but not so greatly as here. To the north, in the mining area at Tombstone, the basal beds of the Bisbee formation are only locally conglomeratic; elsewhere they consist of fine-grained limy sandstone that has been altered to jasperoid ("novaculite" of F. L. Ransome's unpublished notes, and of Butler, Wilson and Rasor, 1938, p. 19). In the Dragoon Mountains, the formation generally has a series of limestone conglomerates at the base, and in places the conglomerates attain several scores of feet in thickness. Such rocks, presumably representing a part of the formation not far above the base, are common in the area between North Courtland and Middlemarch Canyon, though the actual base of the formation is exposed only in the northerly localities.

The bulk of the Bisbee formation consists of mudstone and sandstone or quartzite, with a few thin beds of limestone. Most of the mudstone beds are maroon, although a few are black or green; the sandstone and quartzite beds are commonly gritty, crossbedded, and brown to buff on weathered surfaces. They range in thickness from a few inches to as much as 60 or even 80 feet but average commonly from 2 to 10 feet in thickness. Beds are generally lenticular, although many individual beds are readily traced for several hundred feet.

In the mining area at Tombstone at least six beds of limestone occur near the base of the Bisbee formation.

The lowest and thickest is as much as 40 feet thick in places. These six beds of blue-gray and silty limestone contain abundant marine fossils. The formation contains at least two other beds of limestone 2 miles to the southwest; these contain fresh-water faunules. About 2 miles east of Dragoon Camp (Black Diamond), several thin beds of blue-gray shaly limestone occur in the Bisbee formation at a horizon that is many hundreds of feet stratigraphically higher (with respect to the local base of the formation) than these southern beds. The limestones near Dragoon Camp also contain a marine fauna, but so poorly preserved as to be of little service in correlation. The fauna is principally of interest because it shows the persistence, at least at times, of marine conditions during the deposition of the Bisbee formation as far north as Dragoon Camp.

Everywhere in the area the top of the Bisbee formation is an erosion surface, either ancient or recent. Accordingly, even if exposures were much better and structural complexities much less, it would be impossible to determine the original thickness of the formation. Under these conditions it is possible only to estimate the minimum thickness of the rocks. A careful study of the much-faulted and metamorphosed strata exposed in the mining district at Tombstone has been made by Messrs. J. P. Lyden, R. M. Hernon, Neil O'Donnell, and C. E. Higdon, who kindly supplied the following composite generalized section, synthesized from many partial sections measured in the Tombstone district.

Generalized composite section, Bisbee formation, Tombstone Hills.

	Feet
Erosion surface.	
1. Sandstone and shale, alternating; a few 10-foot limestone conglomerate beds; shale members chiefly red or maroon; sandstone beds buff to brown, a few gray or white; sandstone members range from 20 to 170 feet in thickness, predominate over the shale	1, 040±
2. Sandstone, buff, gray, and white, some interbedded gray-green hard shale; thick bedded	220
3. Shale, gray to green, hard and siliceous, a few thin buff sandstone beds	540
4. Sandstone, buff, white, and brown, a few green shale beds, at least one thin bed of limestone	422±
5. Shale, green and bluish, some conglomerate	58
6. Limestone, massive, blue, cherty	25
7. Shale, green, mottled red and green, brown, and yellow	345
8. Limestone	10
9. Shale, some sandy beds	29
10. Shale and limestone, alternating in thin beds	15
11. Shale, greenish, some limy beds	30
12. Limestone	5
13. Shale, poorly exposed	53
14. Limestone	4
15. Shale, gray, green, and black	43
16. Sandstone, yellow	9
17. Shale, red and brown	65
18. Shale, black	14
19. Shale, green and gray, siliceous	42
20. Limestone, "Ten-foot bed" of miners	10
21. Shale, with arkose at base	24
22. Limestone, "Blue limestone" of miners	34
23. "Novaculite," silicified shale, local intercalations of limestone conglomerate	60
Total	3, 097±

The above section cannot be considered accurate because it represents the synthesis of at least four partial sections, the correlations between which are all dubious. Nevertheless, as it was based on very detailed and careful work, there can be little doubt that it is as fair a representation of the stratigraphy of the formation at Tombstone as it is possible to give with the present exposures. It is shown graphically in figure 5. The formation elsewhere in the area is lithologically much the same.

No effort was made to measure a section of the Bisbee formation in the Dragoon Mountains; but from the dips and width of outcrop, it can be seen that there is about 15,000 feet of Bisbee rocks in the section northeast of Walnut Springs, where neither base nor top is exposed. This thickness, though large, is not surprising, as the aggregate thickness of the Bisbee group in the Mule Mountains was measured by Ransome (1904, p. 56) as 4,750 feet, with the top eroded. In the Little Hatchet Mountains, N. Mex., 80 miles to the east, Lasky (1938, p. 524–540) has found a section of Comanche rocks over 17,000 feet thick, of which fully 15,000 feet are of late Trinity (Glen Rose) age. The thinning of the Mural limestone northward from the Bisbee area does not, of course, imply the northward thinning of the clastic rocks above and beneath it. At any rate, whatever the a priori probabilities, the consistent attitudes and gradual changes in strike and dip of the section exposed northeast of Walnut Springs strongly oppose the idea that this section has been greatly repeated by faulting, despite the structural complexities of the mountains to the west.

CONDITIONS OF DEPOSITION

The Bisbee formation contains a few beds of definitely marine origin, at least as far north as the foothills east of Black Diamond Peak. On the other hand, freshwater fossils have been found in the formation between Charleston and the Tombstone Hills. The fossils are confined to a few thin beds, and the great bulk of the rocks are unfossiliferous.

The sandstone beds are commonly current-bedded, with scour on their bases, ripple marks, and considerable grit or even fine conglomerate, and thus give evidence of shallow water at the time of their deposition. The mudstones are generally red, brown, maroon, or

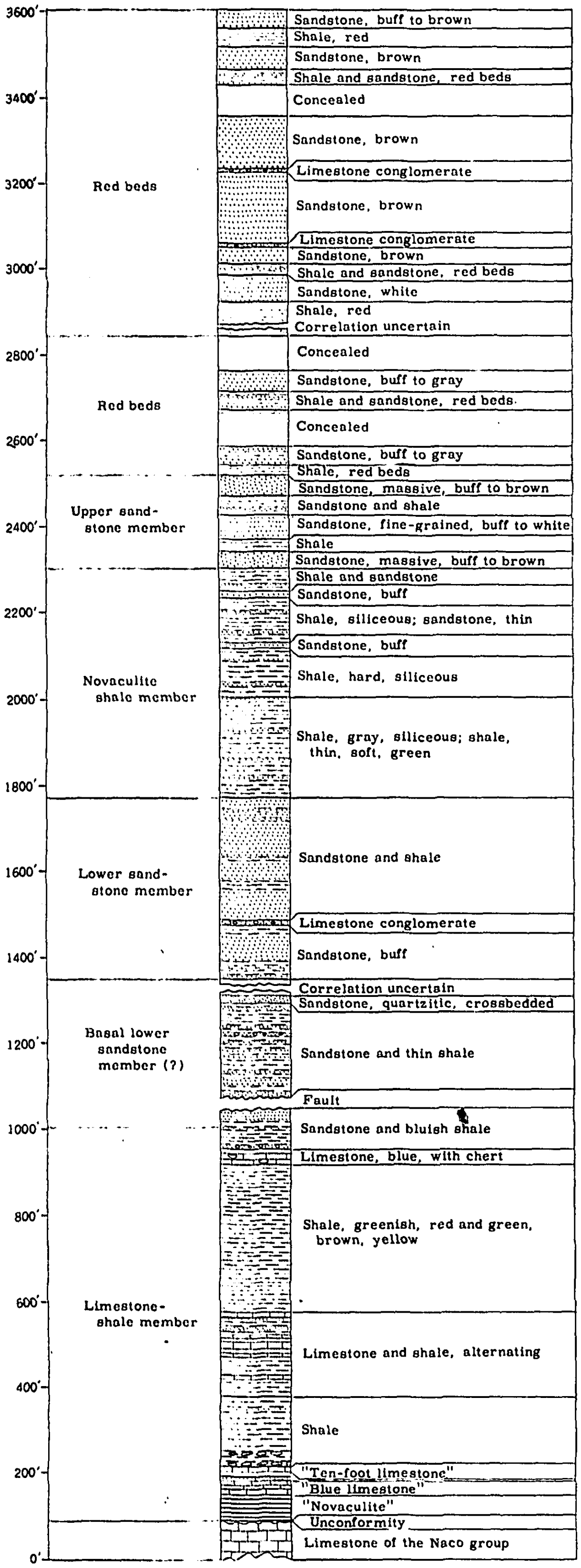


FIGURE 5.—Composite section of the Bisbee formation in the Tombstone mining district. After Lyden, O'Donnell, Hernon, and Higdon (unpublished mine rept., 1937).

green, each mottled by one or both of the remaining hues. These features might be thought to suggest terrestrial deposition, but in view of the sporadic interbedded marine layers, it seems equally or more likely that the formation is of estuarine origin; possibly some of the beds are terrestrial, but some are surely marine. The great thickness of the formation proves that the basin must have subsided along with the sedimentary filling, so that it is not unlikely that at times deposition exceeded subsidence, leading to terrestrial sedimentation, and at other times the subsidence carried the area below sea level, so that there was an incursion of marine water. The lensing out of the limestone of the Comanche toward the north seems to indicate clearly that the northern shore of the estuary lay in that direction. Conditions during the time of Bisbee deposition may have been analogous to those now prevailing along the Gulf of Mexico, though the coarseness of the Comanche rocks indicates that most of the material forming them came from rather nearby sources.

PETROGRAPHIC FEATURES OF THE BISBEE FORMATION USED IN CORRELATION

CONTENT OF VOLCANIC DETRITUS

No systematic study was made of the petrographic details of the Bisbee, but owing to possibilities of misidentification of the several formations in areas of complex structure and intense metamorphism, many grab samples were studied microscopically to determine their mineralogical composition.

All specimens of the sandstones of the Bisbee examined are arkosic, with considerable admixtures of microcline, orthoclase, and plagioclase with the dominant quartz. Many also contain round granules of crystalline calcite or small fragments of limestone. These granules and fragments contrast markedly with the cryptocrystalline calcite that constitutes the cement of many specimens and are therefore thought to be detrital. None of the specimens studied from the Mule Mountains contain any definitely volcanic material. However, several of the sandstones from the Tombstone Hills contain fragments of rhyolitic rocks, with phenocrysts of sanidine and quartz in a devitrified base. Although these rocks contain only subordinate quantities of these volcanic materials, they apparently overlie fossiliferous beds of early Cretaceous age conformably and are therefore referred rather confidently to the Bisbee formation, especially since Cooper's discovery of andesites and rhyolites beneath Bisbee rocks at Walnut Gap, a few miles north of the Benson quadrangle.

In the southern part of the area, the absence of such pre-Bisbee volcanic rocks, even if formerly present, is not surprising, as the Comanche rocks rest unconformably on rocks of Paleozoic age and even on pre-Cambrian rocks. However, in the Tombstone Hills the Bisbee rests on different horizons in the Epitaph dolomite, and the relief of the surface of unconformity is considerable, so that one might expect to find local patches of volcanic rocks preserved, if the Epitaph is the latest formation of Paleozoic age that was deposited here. No such occurrences have been found. This may be because no volcanic rocks were ever present in this area during the post-Epitaph–pre-Bisbee epoch, or it may be explained by subsequent erosion of such rocks. If, as seems likely from the occurrence of younger Permian rocks in the Chiricahua Mountains just to the east, the Epitaph is not the youngest Paleozoic rock deposited here, the pre-Bisbee erosion may have removed a considerably greater thickness of rocks than one might infer from the relatively slight angular discordance beneath the Mesozoic rocks in the Tombstone Hills. The local occurrence of volcanic detritus in the Bisbee formation lends some support to this suggestion, though this detritus may have been supplied from more distant sources.

The question discussed in the preceding paragraph has considerable importance in interpreting the geology of the eastern side of the Dragoon Mountains. In the foothills and pediment bordering the mountains between Barrett Camp and the latitude of Pearce, there is a great thickness of beds here referred to the Bisbee formation. The assignment of much of this series to the Bisbee is made with confidence, because of a few fossils resembling those from the Mural limestone (USNM 17473) were collected in SE¼, sec. 22, T. 18 S., R. 24 E. In nearby localities other fossils, not so well preserved but still identifiable as marine and hence, on regional grounds, of Comanche age, were also found. Between these fossiliferous beds and the faults that bound the mountains to the west, the series appear to be stratigraphically continuous; and, because the tops of the beds all face eastward, although much of the section is overturned, the beds in this interval appear to constitute a conformably underlying part of the Bisbee formation. (See pl. 5.) These rocks, stratigraphically beneath the fossiliferous part of the Bisbee, become increasingly coarse grained downward; and the lowest exposed beds, just east of the fault, are generally conglomeratic, and some are rather coarse boulder conglomerates.

These conglomerates differ from the Glance conglomerate of the type locality and from other conglomerates in the Bisbee at Tombstone and north of Cochise Stronghold by containing considerable volcanic material. Though limestone cobbles and boulders dominate the conglomerates, as is common in other areas, considerable proportions of rhyolite cobbles are also present, and there is much rhyolitic material in the matrix. Inasmuch as very abundant volcanic material exists in the post-Comanche rocks of the area and is all but lacking elsewhere in the rocks of known Comanche age, considerable work was done in the transitional zone between the fossiliferous beds and these conglomerates that contain the abundant volcanic debris in order to ascertain the stratigraphic relations in more detail. No evidence of any fault was found between them; and the attitudes, both as to strike and dip, seem to change gradually and continuously between the rocks in question. Accordingly, the conglomerates are here regarded as part of the Bisbee formation, and the structural interpretation of this area is based upon this correlation. The interpretation is strengthened somewhat by the fact that volcanic debris is also present, though sparingly, in the Bisbee formation of the Tombstone Hills, as mentioned previously.

In the belt of thrust shingles that trends eastward from South Pass, just north of Barrett Camp, there are many slices of volcanic rocks and of conglomerates that contain volcanic boulders mingled with the slices of Paleozoic rocks and rocks of definite Bisbee formation. Also in the reentrant of the Dragoon thrust at South Pass, andesitic volcanic rocks underlie a considerable area. (See pp. 68–70.) Because the volcanic rocks at Walnut Gap are apparently in normal stratigraphic relationship beneath the Bisbee formation, these volcanic rocks are considered early Comanche or older, although the volcanic-bearing conglomerate to the east is very probably Comanche and the conglomerates of the Bisbee contain rhyolitic rather than andesitic detritus.

METAMORPHOSED FACIES

No difficulty is experienced in recognizing the Bisbee formation in its hornfels facies in areas south of Middle Pass, either in the Dragoon Mountains, the Tombstone Hills, or near Boquillas. In all these areas, alteration near the post-Bisbee intrusive rocks has been generally mild and local and affected rocks that, though previously complexly deformed, had not undergone pervasive shearing. Accordingly, it is generally possible to trace an individual bed from its more altered facies into one that is readily recognized as representative of the unaltered sedimentary facies of the Bisbee. The intercalated coarser clastic rocks are commonly altered to quartzite near the Schieffelin granodiorite. North of Lewis Springs and both south and east of Tombstone, such quartzite beds have been altered and recrystallized into mosaic-textured rocks that contain quartz, microcline, oligoclase or albite, and epidote or actinolite, along with accessory magnetite. The interbedded shale or mudstone beds have locally been altered to jasperoid in the Tombstone mining district, though generally they have been altered to hornfels containing grossularite, chlorite, orthoclase, biotite, actinolite, albite, quartz, and sericite, with or without residual calcite. Most of the hornfels is aphanitic, and none of these minerals can be recognized with a hand lens. Many such hornfels beds can be traced along the strike into the normal maroon or greenish mudstone of the Bisbee, and the only beds with which they might be confused in mapping are those of the lower part of the Earp and of the upper part of the Epitaph dolomite. Such rocks occur north of Boquillas, but the occurrence of interbedded dolomites permits the distinction of the shales of the late Paleozoic from those of the Bisbee.

In Middlemarch Canyon most of the rocks referred to the Bisbee retain enough of their unmetamorphosed characteristics to permit confident recognition despite alteration. Toward the head of the canyon, the alteration is more intense. A hornfels specimen, collected just east of the narrow sliver of Cochise Peak quartz monzonite 0.7 mile southeast of Cochise Peak (pl. 5), consists of epidote, zoisite, hornblende, orthoclase, quartz, and sericite. This association suggests a lime content that would be rather high for the average mudstone of the Bisbee, but appears not sufficiently anomalous to require revision of the field assignment of the rock to the Bisbee. Two other specimens collected from near the fault that bounds the main mass of Cochise Peak quartz monzonite at the Cobre Loma prospect, half a mile south of Cochise Peak, are closely associated with sheared limestone conglomerate that has been altered to hornfels. This may account for the original dolomitic content suggested by present mineral composition, as a dolomitic character is anomalous in rocks of the Bisbee formation. These rocks are calc-hornfels, one consisting of wollastonite, diopside, calcite, quartz, epidote, tremolite, and grossularite and the other of grossularite, quartz, diopside, calcite, much magnetite, and small amounts of an unidentified mineral. This mineral is in radiating plates that partly fill the interstices between euhedral garnet crystals. It is colorless, biaxial positive, with an axial angle of about 15°, $\gamma=1.543$, α and β 1.532, ± 0.003, with negative elongation, and is insoluble in acid.

These rocks at the Cobre Loma prospect are also anomalous in other respects, as there are fully 400 feet of highly carbonaceous black slates overlying the finely banded hornfels just described. Such rocks have not been found anywhere else in the area of this survey and may belong to a formation younger than the Bisbee. The structure is so complex here, and the posttectonic thermal metamorphism so intense, that the occurrence of normal Bisbee mudstones along the strike a few hundred feet to the south cannot be given much weight in correlation of these rocks with the Bisbee. However, in absence of recognized sedimentary rocks of this character among the formations of pre-Cretaceous age and because of their association with limestone conglomerates like those in the Bisbee, it has been thought best to class these rocks with that formation.

From the latitude of Cochise Peak northward to the quadrangle boundary, the alteration of the older rocks by the Stronghold granite has been very intense, and the structural complexities are such that the recognition of many rocks in their hornfels facies is difficult and perhaps locally impossible. Here all the rocks have undergone intense differential movements, probably chiefly prior to the injection of the plutonic rocks; and thermal metamorphism caused by the Stronghold granite has been superposed upon this older metamorphism.

Although in local areas individual clastic beds of the several Paleozoic formations, such as the Bolsa quartzite, the upper parts of the Abrigo limestone and Epitaph, and the lower parts of the Martin and Earp, may all resemble the Bisbee formation, they are ordinarily readily recognized by their associated carbonate rocks. The principal difficulty is in distinguishing between the Pinal schist and the Bisbee. In small outcrops, indeed, I have been unable to find criteria for the discrimination of these formations in this region of intense alteration. In larger outcrops, however, it is generally possible to find features that strongly suggest the derivation of these altered schists from either one or the other of these formations. Quartzite beds 10 to 30 feet thick, alternating with somewhat thicker layers of mica schist, have not been recognized as normal constituents of the Pinal elsewhere in the map area, whereas they are to be expected in the metamorphic facies of the Bisbee. Such intercalations of quartzite and mica schist have been assigned consistently to the Bisbee, and this assignment has in many places been confirmed by the recognition of highly sheared limestone conglomerates associated with them. On the other hand, abundant greenstone schists would not be expected to result from metamorphism of the Bisbee, whereas they are common in undoubted Pinal outside this highly metamorphic area. With the aid of these criteria, and the local relicts of less-metamorphosed and hence recognizable Bisbee rock, it has proved generally possible to assign most large exposures of schist to one or the other of these formations with some confidence. The feature that one might expect to prove most useful—the recognition of superposed schistosity over relicts of an older one in the Pinal—cannot be utilized. Schistose limestone conglomerates that must almost certainly be of Bisbee age can be found with a second systematic foliation transecting an older. The presence of abundant graphite suggests the Bisbee rather than the Pinal, but this is not a criterion that I would wish to rely upon, as graphitic schist, even if present in the Pinal outside these hornfels areas, would not be expected to crop out abundantly and the failure to recognize it elsewhere may not safely be taken to indicate its absence from the Pinal.

Although wide areas of these rocks have been altered to schist and hornfels, sporadic masses have undergone much less alteration, and quartzite beds that retain recognizable pebbles and even crossbedding are found in some places. Thus the Bisbee rocks in this northern area comprise limestone or marbleized conglomerates, quartzites, muscovite-quartz schists, muscovite-chlorite-quartz schists, andalusite-biotite-muscovite schists, graphite-muscovite schists, graphitic oligoclase-zoisite-andalusite schist, and massive andalusite-graphite hornfels. Many of the schists are conspicuously "knotted," and crystals of chiastolite as much as 3 centimeters long are abundant.

Some of the limestone conglomerates, though sheared out, are mineralogically nearly the same as their unaltered counterparts. A specimen from near the Fourr Ranch, is illustrated in plate 3*C*. Other specimens have been more altered, with the formation of epidote, diopside, orthoclase, and sericite, though the forms of the pebbles have been preserved.

Relicts of crossbedding are recognizable in some of the quartzite beds, and other beds have been altered to quartz schists with a little muscovite between the grains of quartz, microcline, albite, and zoisite. Both varieties are wholly crystalloblastic. Diopside, orthoclase, zoisite, and a little tremolite, along with the dominant quartz, in a granulitic texture, evidently represent some of the more limy sandstones.

A representative specimen of the knotted schist from a point southeast of the Fourr Ranch house consists of quartz, graphite, pale-green biotite, and muscovite as the principal minerals. Tourmaline, strongly dichroic from pale blue to deep blue green, occurs in rosettes in this rock. The biotite is in large part deformed and rotated, and the muscovite is in two generations, the plates of one deformed with the biotite and the straight plates of the other crossing the older trends in the rock. Pseudomorphs of andalusite are recognizable by their characteristic cross sections; but this mineral, which formerly constituted perhaps 10 percent of the rock, has been completely transformed to muscovite. There has been some shearing of the rock after the formation of the andalusite, for some of the forms are broken and displaced. The alteration to muscovite must have followed this displacement, as otherwise the retention of the form of the andalusite would seem inexplicable. (See pl. 4*C*.) In other specimens, zoisite replaced part of the andalusite along with the muscovite.

Spotted schists in Jordan Canyon, referred to the Bisbee, are similar to the specimen just described, though in some the biotite has been altered to chlorite and in others there is abundant zoisite and magnetite in addition. (See pl. 4*B*.) One specimen from this canyon consists of 50 percent muscovite, 20 percent actinolite, 15 percent zoisite, 10 percent diopside, 5 percent calcite, and neither quartz nor biotite. The texture is strongly schistose, rather than that of a hornfels; and much of the actinolite seems to have formed at the expense of diopside and zoisite.

Other specimens collected nearby preserve surprisingly good relicts of their original detrital textures, though curving plates of micas bound the lenses of detrital quartz. In fact, the great local variation in textures and mineralogy of these schistose rocks is one of their most striking features. It seems evident that the complex structure of this part of the area has resulted in bringing rocks from several different environments and with widely different metamorphic histories into close areal association. Without a very much more detailed study than was possible during this survey, it is fruitless to discuss the petrology of these rocks in further detail.

It is clear that the discrimination of the Bisbee formation from the Pinal in the area of intense metamorphism can be at best arbitrary in small outcrops, but in larger exposures the associations usually permit a fair amount of confidence. The remarkable similarity between the Pinal schist and some of the metamorphic facies of the Bisbee group at Bisbee has been commented on by Ransome (1904, p. 101–102).

It should be pointed out that D. J. Cederstrom (1946, pl. 1) regards the schist mass extending north from China Peak into Stronghold Canyon as Cretaceous, whereas I have mapped it as Pinal because of the abundance of greenstone schists. However, my examination of this mass was not as detailed as could be wished, even on the scale of the accompanying map, and it may well be that this body should be correlated with the Bisbee.

AGE AND CORRELATION

The Bisbee group was assigned to the Lower Cretaceous by T. W. Stanton (1904, p. 70) who pointed out its relationship to the Trinity of Texas. In company with J. B. Reeside, Jr., and with the assistance of Edgar Bowles, a rather extensive series of collections was made from the Bisbee group during this survey. The study of these collections by Mr. Reeside has served to confirm the Trinity age of the group and to emphasize that most, if not all, of it is referable to the Glen Rose, the upper part of the Trinity of Texas. The known lateral variations of the strata of Trinity age in southern Arizona and southwestern New Mexico are such as to preclude the possibility of formational correlations between these areas, but it may be mentioned that many of the lithologic varieties of the Bisbee strata can be closely duplicated at several horizons in the thick Lower Cretaceous section of the Little Hatchet Mountains, 80 miles to the east of this area (Lasky, 1938, p. 535–538). The rocks assignable to the Glen Rose equivalents in the Little Hatchet Mountains are more than 17,000 feet thick. They also show abrupt and remarkably great facies changes and doubtless accumulated at the border of a geosyncline. The area of this report was also probably near the border of the geosyncline of Glen Rose time.

Reeside has kindly submitted the following discussion of the fossils collected during this survey.

CRETACEOUS FOSSILS

By John B. Reeside, Jr.

In some respects the fossils in this collection are unsatisfactory for study. Many are preserved as none too distinct molds; others do not break from the matrix very readily and therefore retain few details. Many of the species are undoubtedly unnamed new forms. On the other hand, it seems to me, enough species are close to species named from the Trinity group of Arkansas and Texas to justify the conclusion that there is little difference in age between the Arizona horizons represented and the Trinity.

One of the interesting features of the collection is the apparent absence of the *Exogyra quitmanensis* fauna that is so conspicuous in the Little Hatchet Mountains of southwestern New Mexico, along the Rio Grande in Texas, and reported to occur in Sonora. I would infer, with some reservation, that the time of the *E. quitmanensis* fauna is represented by unfossiliferous Morita strata below the horizons of this collection.

The assemblage is a pelecypod-gastropod facies that in its almost total lack of ammonites contrasts with the faunas on the international boundary in horizons below the massive Mural limestone. Perhaps the present collections represent habitats nearer shore than those from the ammonite-bearing facies.

The lots from the "Blue limestone" at Tombstone (USGS 17456, 17470, 17471, 18132) seem to me to belong to the same general fauna as the main body of the collection.

Lots USGS 17813 and 17814, considered in the field to be possibly "Upper Cretaceous or Tertiary," are marine and of wholly different facies from any known Upper Cretaceous or Tertiary in the region. They are, on the other hand, like the regional Lower Cretaceous in facies, and lot 17814 particularly appears to be like the lower Mural. I doubt any great difference in age from the Mural.

Lots USGS 17472 and 17472A are a fresh-water fauna which I cannot correlate. The age assignment will have to depend on the physical relationships of the containing beds.

In the appended lists I have made almost no specific identifications and have queried many of the generic identifications. It is likely, however, that when Professor Stoyanow's study of the faunas of the region is completed, names will be available for many of the forms that are present. I note that T. W. Stanton (1904) used a number of Texas and Arkansas names without reservation. Some of these names are those I have used in comparisons and have probably been applied to the same species.

The individual lists are as follows:

USGS 17393. Bottom of south branch of Dixie Canyon, 2 miles above Stevenson Ranch, near north edge Mule Mountains, Bisbee quadrangle; 84 feet below base of massive Mural limestone

Cucullaea? sp.
Gervillia? sp.
Ostrea sp., simple elongated form
Gryphaea? sp.
Trigonia aff. *T. stolleyi* Hill
Trigonia aff. *T. taffi* Cragin
Trigonia aff. *T. concentrica* Cragin
Camptonectes? sp.
Pleuromya sp.
Homomya sp.
Homomya? sp., a much elongated form
Anatina sp.
Arctica cf. *A. roemeri* (Cragin)
Arctica? sp. (cf. *"Chione" decepta* Hill)
Eriphyla aff. *E. pikensis* Hill
Lucina sp.
Cardium sp.
Protocardia? sp.
Isocardia? sp.
Tellina sp.
Venerid? pelecypods, undetermined
Gastropods, undetermined small molds
Parahoplites? sp., a fragment
See also USGS 17465.

USGS 17394. Bottom of canyon 2,000 feet east-northeast of 6,108-foot peak, 2 miles due west of Stevenson Ranch, Mule Mountains, near south edge of Pearce quadrangle; 5 feet below base of massive Mural limestone

Fragments of a large ostreid, probably *Ostrea* sp. I can find no pieces that suggest *Exogyra*.

USGS 17395. Same locality as USGS 17394; not over 25 feet below base of massive Mural limestone

Ostrea sp.
Trigonia aff. *T. stolleyi* Hill
Nerinea hicoriensis Cragin
Actaeonella sp.

USGS 17396. 1,500 feet due east of BM 5523, 1 mile west of mouth of Johnson Canyon, Mule Mountains, near south edge of Pearce quadrangle; 10 feet or less below base of massive Mural limestone

Pteria singleyi (Cragin)
Anomia cf. *A. texana* Hill
Protocardia sp.
Corbula aff. *C. pyriformis* (Meek)
Glauconia sp.
Cerithium sp., small mold
Fusus? sp.

USGS 17397. West slope of conical hill 1 mile east of Potter Ranch, east of Abbot Canyon, east side of Mule Mountains, Pearce quadrangle; in 5½-foot limestone 10 feet above sandstone taken as top of Morita formation

Cliona? sp., borings in *Ostrea*
Rhynchonelloid indet.
Ostrea sp., large form much like that of 17394
Nerinea hicoriensis Cragin
Actaeonella sp.

USGS 17398. Same locality as USGS 17397; 40 feet above sandstone taken as top of Morita

Serpula sp.
Ostrea sp., fragments
Arctica? sp., fragments
Nerinea hicoriensis Cragin

USGS 17399. Same locality as USGS 17397; shaly limestone (2 feet thick) 45 feet above sandstone taken as top of Morita

Ostrea sp.
Anomia cf. *A. texana* Hill
Homomya? sp., elongated form like that in lot 17393
Trigonia sp., a scabrid form
Arctica cf. *A. roemeri* (Cragin)
Protocardia sp.
Cyprimeria? sp.
Lunatia pedernalis (Hill, not Roemer)

USGS 17400. Same locality as USGS 17397; in 4-foot limestone 54 feet above sandstone taken as top of Morita

Serpula sp.
Echinoid spines
Arca? sp.
Trigonia aff. *T. taffi* Cragin
Trigonia aff. *T. stolleyi* Hill
Lima? sp.
Arctica? sp.
Eriphyla cf. *E. pikensis* Hill
Eoradiolites? sp.
Lunatia pedernalis (Hill, not Roemer)
Cerithium sp.

USGS 17401. Same locality as USGS 17397; 2-foot limestone 82 feet above top of Morita

Cliona sp.
Serpula sp.
Terebratula? sp.
Cucullaea aff. *C. terminalis* Conrad
Ostrea sp., large form
Trigonia aff. *T. stolleyi* Hill
Eriphyla aff. *E. pikensis* Hill
Protocardia aff. *P. stonei* Cragin
Corbula? sp.
Nerinea sp.

USGS 17402. Same locality as USGS 17397; 88 to 91 feet above sandstone taken as top of Morita

Serpula sp.
Grammatodon? sp.
Cucullaea aff. *C. terminalis* Conrad
Ostrea crenulimargo Roemer, small individuals
Trigonia aff. *T. taffi* Cragin
Trigonia aff. *T. stolleyi* Hill
Neithea sp.
Homomya? sp., elongated form
Astarte sp.
Eriphyla aff. *E. pikensis* (Hill)
Crassatellites sp.
Lucina? sp.
Cardium, sp. small
Protocardia sp., small
Corbis? sp.
Tapes? sp., large compressed shell
Venerid pelecypods, small
Corpula sp.
Turbonilla sp.
Turritella sp.
See also 17467.

USGS 17403. Same locality as USGS 17397; 170 feet above top of sandstone taken as top of Morita in a 2½-foot limy sandstone

Glauconia aff. *G. branneri* (Hill), like an unnamed form from the Glen Rose of Texas
Aporrhais sp.
See also 17468.

USGS 17404. Same locality as USGS 17397; 188 feet above top of sandstone taken as top of Morita in sandy limestone

Cliona sp.
Serpula sp.
Ostrea sp., large form
Homomya sp.
Turritella sp.
Actaeonella sp.

USGS 17405. Same locality as USGS 17397; 248 feet above sandstone taken as top of Morita, 6 feet above base of massive limestone

Actaeonella? sp.
Turritella? sp.

USGS 17406. Same locality as USGS 17397; 250 feet above sandstone taken as top of Morita, 10 feet above base of massive limestone of USGS 17405

Fragments of gastropods, pelecypods, echinoids, and serpuloids, none determinable.

USGS 17407. Same locality as USGS 17397; 262 feet above sandstone taken as top of Morita; top of massive limestone of USGS 17405

Small oysters and fragments of other fossils, none determinable.

USGS 17408. Same locality as USGS 17397; 313 feet above sandstone taken as top of Morita; base of 14-foot sandy limestone

A coquina of shell fragments, none determinable. Some suggest *Toucasia*.

USGS 17409. Same locality as USGS 17397; 327 feet above sandstone taken as top of Morita and 7½ feet below massive Mural limestone.

Serpula sp.
Ostrea sp., fragments of large species
Gryphaea? sp.
Cucullaea? sp.
Arctica? sp.
Trigonia sp.
Turritella seriatimgranulata Roemer var.
Trochus (*Tectus*)? sp.
Nerinea? sp.

USGS 17410. 3,000 feet due east of BM 5523, in small tributary of Johnson Canyon, just above the mouth; east side of Mule Mountains, Pearce quadrangle, Arizona; approximately 190 feet below massive limestone of Mural

Serpula sp.
Nucula? sp.
Arca sp.
Grammatodon sp.
Pteria sp.
Ostrea sp., juvenile
Trigonia aff. *T. taffi* Cragin
Trigonia aff. *T. stolleyi* Hill
Anomia sp.
Homomya sp.
Arctica? sp.
Astarte sp.
Eriphyla cf. *E. pikensis* Hill
Anthonya sp.
Protocardia aff. *P. hillana* Sowerby
Protocardia aff. *P. stonei* Cragin
Venerid, undetermined
Mactra? sp.
Panope sp.
Lunatia sp., small
Lunatia? sp.
Aporrhais sp.
Aporrhais? sp.

USGS 17411. Same locality as USGS 17410; 85 feet below massive Mural limestone and 35 feet below a surpuloid bed like that of USGS lot 17406

Ostrea sp., fragments of large form
Cucullaea? sp.
Arctica sp.
Isocardia sp.
Isocardia? sp.
Purpuroidea sp.

USGS 17456. 500 feet southeast of railroad station in Tombstone; limestone in lower part of Bisbee formation

A coquina of a small, simple species of *Ostrea;* no other genera recognized.
See also USGS 17470.

USGS 17457. North spur of The Three Brothers hills, just north of porphyry contact; lower part of Bisbee formation

Cross sections of small pelecypods; matrix does not break away and not enough was seen for identification.

USGS 17465. Same locality and horizon as USGS 17393

Trigonia aff. *T. stolleyi* Hill
Trigonia aff. *T. taffi* Cragin
Trigonia aff. *T. concentrica* Cragin
Arctica? sp. (cf. "*Chione*" *decepta* Hill)
Eriphyla aff. *E. pikensis* Hill

USGS 17466. Same locality as USGS 17393 and 17465 but loose material

Arctica?, probably like species in 17645, internal molds
Corbis? sp.
Ostrea sp.

USGS 17467. Same locality as USGS 17402

Nucula? sp.
Trigonia aff. *T. stolleyi* Hill
Astarte sp.
Protocardia? sp.
Corbula sp.
Turritella sp.

USGS 17468. Same locality as USGS 17403

Turbonilla sp.

USGS 17469. Same locality as USGS 17397. Halfway up Mural outcrop

Porocystis globularis (Giebel), a standard Glen Rose species

USGS 17470. Same locality and horizon as USGS 17456

Gervillia? sp.
Ostrea sp., small simple form
Pleuromya? sp.
Veniella? sp.
Eriphyla aff. *E. pikensis* Hill
Tapes? sp.
Tellina? sp.
Donax? sp.
Mactra? sp.
Tylostoma sp.

USGS 17471. Same locality and horizon as USGS 17456 and USGS 17470, but across gulch

Volsella sp.

USGS 17472. SE¼ sec. 28, T. 20 S., R. 22 E., in creek; Bisbee formation, probably low in formation

Helisoma ("*Planorbis*") sp.
Valvata sp.
Viviparus? sp.
Cyprid ostracode
Small round bodies, possibly coprolites
Branching, irregular rods, undetermined
Fresh-water fauna

USGS 17472 A. Same locality as USGS 17472; slightly different horizon

Helisoma ("*Planorbis*") sp.
Fresh-water fauna.

USGS 17473. East of Black Diamond Peak in SE¼ sec. 22, T. 18 S., R. 24 E.; thin blue limestone in Bisbee formation

Serpula sp.
Anomia sp., small, simple form

Astarte sp.
Natica? sp.
Turritella? sp.
A marine fauna, not markedly different from the larger Mural fauna.

USGS 17476. Spur 2,000 feet south-southwest of Potter Spring, Abbot Canyon, Mule Mountains; elevation 5,400 feet; about 500 feet below lower Mural, in Morita formation

Coral, possibly *Orbicella* sp.
Serpula sp.
Large boring, possibly worm
Cucullaea sp.
Ostrea sp., large simple form
Trigonia aff. *T. stolleyi* Hill
Trigonia aff. *T. taffi* Cragin
Trigonia aff. *T. concentrica* Cragin
"*Pecten*" *stantoni* Hill var., as in lot 17475
Neithea sp.
Lithophagus sp., borings and shells
Volsella sp.
Homomya sp.
Arctica sp.
Astarte sp., as in lot 17402 and other lots
Cardita sp.
Cardium? sp.
Venerid? pelecypod
Panope? sp.
Tylostoma sp.
Glauconia aff. *G. branneri* (Hill), as in lot 17403
Nerinea sp., a small form
Cerithium? sp.

USGS 17812. 2,000 feet east, 1,200 feet north of SW. cor. sec. 31, T. 18 S., R. 25 E., Bisbee formation

Many small gastropods in such poor condition that I hesitate to apply even generic names. Some forms suggest *Nerinea*, others *Actaeonella* and other genera. The fauna is marine, but I can say little more.

USGS 17813. NW¼ sec. 18, T. 20 S., R. 24 E.; obscurely related limestone

Serpula sp.
Bryozoan
Echinoid spines
Heteraster
Ostrea or *Anomia* sp.
This is a marine fauna and on regional grounds could not be younger than Early Cretaceous. I cannot place it closer.

USGS 17814. NW¼ sec. 18, T. 20 S., R. 24 E.; limestone

Ostrea sp., fragments
Eriphyla aff. *E. pilensis* Hill
Isocardia? sp.
Glauconia aff. *G. branneri* (Hill) as in lots 17403, 17476
Undetermined gastropods
This small fauna seems to me to differ little from the general Trinity fauna, and I doubt that it is younger than Mural.

USGS 18132. "Blue limestone at Tombstone." Collected by B. S. Butler

Veniella? sp.
Tellina? sp.
Apparently same forms as in lot 17470.

USGS 18136. NE. cor. sec. 17, T. 18 S., R. 24 E. (east of Black Diamond Peak), limestone in Bisbee formation

These specimens contain many fragments of pelecypods and gastropods that show the rock to be marine, but I am unable to uncover enough of any one shell to determine it. Some of the gastropods in cross section suggest *Turritella* but are not beyond question.

POST-COMANCHE–PREVOLCANIC UNCONFORMITY

The interpretation of the post-Comanche history of the area is greatly handicapped by the lack of fossils in the rocks intermediate in age between the Bisbee group and the Gila conglomerate. Most of these rocks are igneous; but though many are surficial volcanic rocks and associated with terrestrial sedimentary deposits, the dearth of fossils and the absence of any widespread key beds within them renders reconstruction of the details of the history of this time interval indefinite. The only pre-Gila rocks found in depositional contact on the Bisbee are the S O and Bronco volcanics, whose ages may be anywhere between Late Cretaceous and Miocene. Each of these formations rests with pronounced local unconformity upon the Bisbee. But little likelihood exists that the same unconformity is represented in both localities, as the Bronco volcanics are older than the local thrust faults and the S O volcanics are younger. All that can be said with confidence is that at some time after the deposition of the Bisbee formation strong structural disturbances began, that igneous activity occurred and volcanic rocks and associated terrestrial sediments were deposited, and that deformation and igneous activity followed at several intervals through a geologically long time. On the information at hand, it seems impossible to evaluate the relative significance of these periods of deformation and erosion or to refer any particular one to a definite geologic date—much less to interpret the extent and detailed relationships of any single unconformity.

TERTIARY SYSTEM

GENERAL STATEMENT

In the area of this survey there are large volumes of rocks younger than the Bisbee formation and older than the Gila conglomerate, of Pliocene age. These include intrusive rocks, extrusive volcanic rocks, and subordinate sedimentary rocks. No fossils have been found in them; as a result their ages are uncertain with reference to the standard geologic time scale, and their local variability makes even some of their mutual age relations doubtful. General relations suggest a Tertiary age, though some volcanic rocks of definite Late Cretaceous age are known in Arizona (Ross 1925, p. 25–28) and some of the local formations may also be pre-Tertiary. The present assignment, thus, must be understood as reflecting the probability that most of these rocks are Tertiary and the lack of evidence that any are older.

In absence of key horizons or fossils, these rocks have been subdivided on the basis of structural relations. Thrust faults have been found in many parts of the area; some of the rocks are older; others are younger than the local thrusts. The several thrust faults possibly represent separate orogenic episodes—perhaps as widely separated in time as pre-Eocene and Miocene—but in absence of definite evidence that this is so, it has seemed convenient to assume that all the thrusts of the area belong to a single epoch and to use this assumption as a basis for dividing the formations of post-Bisbee and pre-Gila age into two groups. In view of the long and complex history of orogeny as worked out in other areas of the Cordillera (Nolan, 1935, p. 63–64; Nolan, 1943, p. 171–187; Spieker, 1946), it should be borne in mind that this classification is one of convenience only and is not supported by any objective evidence. Thus, some of the rocks here called younger than the local thrusting possibly are actually older than some of those older than the local thrusting elsewhere in the map area.

IGNEOUS ROCKS OLDER THAN LOCAL THRUST FAULTS

TOMBSTONE AREA

BRONCO VOLCANICS

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Bronco volcanics are typically exposed northeast and north of Bronco Hill.[7] A brief description in which the name was formally proposed appeared in 1945 (Gilluly, 1945, p. 645). The outcrop of the formation in this area covers about 3½ square miles. Smaller bodies of volcanic rocks referred to this formation are found to the southeast, near Lewis Springs, west of the San Pedro River in the low hills that extend northward from a point about 2 miles southeast of Brookline to the river near the old mill site at Contention, and in the hills near Boquillas.

The Bronco volcanics are not topographically prominent; most of the exposures are in the pediment northeast of Charleston and in the dissected edges of the pediment to the west of the river. Only low hills of this formation project above these smooth erosion surfaces.

GEOLOGICAL RELATIONS

The Bronco volcanics rest on the Bisbee formation in the hills north of Lewis Springs and northeast of Bronco Hill. At most of the northern exposures, which are not good, the two formations appear to be essentially conformable, though the presence of a conglomerate that contains boulders of Bolsa quartzite, sandstone of the Bisbee formation, and limestone of Paleozoic age suggests that local disturbance must have occurred during the interval between the deposition of the two formations. The underlying Bisbee formation, though nearly all sandy, has no coarse conglomerates at any stratigraphic horizons exposed nearby. Toward the south the evidence for unconformity becomes stronger. In the hills due east of Bronco Hill the base of the volcanic rocks transects about 100 feet of the Bisbee formation in about 1,000 feet along the contact. In the valley that separates the hills east of Bronco Hill from those north of Lewis, Springs, the Bisbee formation is highly deformed and isoclinally folded, whereas the contact of the overlying volcanic rocks is smoothly sinuous and fails entirely to show comparable structure. On the west bank of the San Pedro River, about three-quarters of a mile north of Lewis Springs, the Bisbee formation strikes N. 80 E. and dips about 15° N., whereas the volcanic rocks that rest on it strike N. 10° E. and dip 20° W., showing conclusively that there is a strong angular discordance between the two formations.

The only stratified rocks that overlie the Bronco volcanics are the late Tertiary and Quaternary strata of the San Pedro valley. Pliocene fossils have been found in these rocks a short distance to the north and serve to show that the volcanic rocks here are at least pre-Pliocene in age. The volcanic rocks have been invaded, deformed, and altered by the Uncle Sam porphyry, the Schieffelin granodiorite, and andesite porphyry east-northeast of Bronco Hill and many andesitic dikes.

STRATIGRAPHY

The Bronco volcanics include two principal varieties: a dominantly andesitic lower part and an upper part that is chiefly quartz latite tuff. No attempt was made to measure the relative proportions of the many facies of the highly variable and poorly exposed formation, but the composition of the lower member is estimated to be at least two-thirds, perhaps three-quarters, flow breccia, and the rest flows, whereas the upper siliceous part is dominantly tuffaceous with only a few flows.

At the base, the formation locally has a conglomerate composed of volcanic material but containing many rounded boulders of quartzite (Bolsa), sandstone (Bisbee), and limestone (Paleozoic). The matrix of the conglomerate is andesitic. Overlying this member, where it is present and elsewhere constituting the basal member of the formation, is andesitic flow breccia.

[7] The name "Bronco Hill," used on the Geological Survey's map of the Benson quadrangle, is probably a corruption of "Bronkow." The Bronkow mine, well known in the early days of mining in the Tombstone district, lies just to the north and the hill was doubtless named for it.

This member, which contains sporadic interbedded flows, is at least 3,500 feet thick, as exposed north of Bronco Hill.

Quartz latite tuff overlies the andesitic member. The contact between the two is irregular, and perhaps interfingering, though the irregularities are possibly due simply to an uneven upper (constructional) surface of the andesitic rocks at the time that the volcanic extravasations changed from andesitic to quartz latite. Some of the apparent irregularities are probably due to faults. The quartz latite member is difficult to measure because of the disturbances near the contacts of the intrusive rocks. A minimum thickness as exposed northeast of Charleston is about 900 feet, but the wide zone of steep dips just south of the old telegraph road, about 1¼ miles to the north, suggests that perhaps 2,500 feet of rocks dominantly composed of quartz latite overlie the andesitic member. A few andesitic beds are apparently intercalated with the quartzose volcanic rocks in the lower part of this more northerly section.

The structural complexities, poor exposures, and alteration of the rocks combine to prevent a satisfactory estimate of the thickness of the volcanic rocks; however, it seems likely that 5,000 feet is a minimum and 6,000 feet a more likely measure of the formation as a whole.

PETROGRAPHY

ANDESITE

The dominant rock of the lower part of the volcanic rocks is andesitic flow breccia. This rock is gray, greenish gray, or pinkish gray on fresh fracture and weathers to brownish hues. Fragments of andesite as much as 4 feet in diameter occur in the breccia, though much smaller sizes are common, in a matrix of finer andesitic material. Some of the matrix is definitely lava, but much more of it is clastic and suggests that the major part of the formation represents volcanic mudflows. There seems to be no petrographic difference between fragments and matrix. A few beds are composed of fine-grained lithic tuffs, some of which show current bedding and ripple marks and were clearly water-laid. Most of the interbedded flows seem to be composed of essentially identical material, except that they are massive.

In hand specimens the andesite shows phenocrysts of plagioclase ranging between 1 and 4 millimeters in length and somewhat less abundant crystals of hornblende of about the same size in an aphanitic groundmass. Many specimens are bleached to a greenish gray, and in these the outlines of the phenocrysts are indistinct; in the subordinate fresher specimens, the groundmass is red brown.

Thin sections show that nearly all the rocks are considerably altered. Part of this alteration may be simply due to weathering, but in many of the rocks it is presumably due to hydrothermal solutions from the intrusive rocks—the Schieffelin granodiorite and the Uncle Sam porphyry. The dominant primary minerals of the lavas and breccias are plagioclase and hornblende. The plagioclase phenocrysts, where still determinable, generally are sodic labradorite (An_{55} to An_{50}); but some are zoned normally, with the exterior zone as sodic as An_{35}. The groundmass feldspar is very fine grained and generally highly altered, but some is still recognizable as andesine. Most of the hornblende has been altered to calcite or to chlorite, but a few specimens retain sporadic grains of common green hornblende, and others contain brown hornblende, generally with opaque rims of iron oxides. Augite occurs in a few specimens; and biotite, some primary but most secondary after hornblende, occurs in a specimen from the hills west of Boquillas. Many of the rocks near the later intrusions have been contact-altered to hornfels that commonly contain biotite. Some of the hornfels specimens also contain orthoclase, but this mineral has not been detected in the andesites elsewhere. Other primary minerals include the usual accessories: apatite, magnetite, and sphene. The texture of the massive flows and the larger pyroclastic fragments is pilotaxitic, and the rocks are clearly to be classed as andesites. The tuffs, though even more severely altered, apparently contained the same minerals.

Most of the specimens examined are so altered that the primary minerals are only recognizable as pseudomorphs. The plagioclase is generally sericitic, epidotic, or altered to clay; the hornblende, to chlorite, epidote, and calcite.

QUARTZ LATITE AND QUARTZ LATITE TUFF

Near the Bronco mine the siliceous rocks that overlie the andesitic breccias are chiefly fine-grained tuffs, with subordinate flows. The tuffs are light gray, ranging to pinkish and greenish gray; the good lamination indicates deposition in water. The flow rocks are pink to dark gray. The flows show small phenocrysts of quartz and very subordinate plagioclase in an obviously devitrified microcrystalline groundmass. The tuffs also contain identifiable quartz; but owing to intense alteration, plagioclase cannot be identified with a hand lens. As seen in thin sections, some of the flows are spherulitic, some have microlites of sanidine in the groundmass, others are practically argillized glass. A little biotite is the only dark mineral present in them. Thin sections of the tuffs show the same minerals along with calcite. The small amount of plagioclase present is so badly altered that its composition is indeterminable

The siliceous rocks west of the San Pedro River differ somewhat from those near the Bronco mine, but their association with similar andesitic rocks makes it seem likely that they belong to the same formation. In these western and northern localities a little dark-gray obsidian occurs, but most of the rocks, whether flows or pyroclastic, are light pinkish gray on fresh fracture and weather to a light brown. Quartz, plagioclase, and biotite are identifiable in nearly all hand specimens, but a few of the tuff layers are so fine grained as to have no recognizable minerals.

In thin sections the resemblances between the tuffaceous rocks and the flows are so close that they clearly are from the same source. Both contain rounded and corroded quartz, much plagioclase close to An_{35} in composition, and conspicuously red-brown biotite. Potash feldspar does not occur as phenocrysts but is identifiable in the groundmass of some specimens. Some of the rocks carry a few wisps of green hornblende, and some of the biotite crystals are apparently pseudomorphous after amphibole. Both flows and tuffs contain much partly devitrified glass; and small spherulites, presumably of potash feldspar, are common in both.

RELATIONS TO OTHER VOLCANIC SERIES

The Bronco volcanics differ in several respects from most of the volcanic formations exposed to the east. The andesitic members of the S O volcanics have prominent hornblende phenocrysts and few or no plagioclase crystals visible to the naked eye, and the siliceous members contain conspicuous opalescent sanidine phenocrysts along with the quartz and biotite. The andesitic members of the Pearce volcanics have augite as a conspicuous constituent, and their plagioclase is more calcic than that of the Bronco volcanics. The rhyolites of the Pearce volcanics also contain sanidine phenocrysts, which are absent from the siliceous rocks of the Bronco. The Sugarloaf quartz latite of the type locality has no andesitic rocks associated with it, but the quartz latite itself strongly resembles that of the Bronco volcanics. Thus, the Sugarloaf contains quartz, biotite, and andesine (An_{35}) as phenocrysts; and though some sanidine phenocrysts are also found, most of the potash feldspar is contained in spherulitic aggregates in the groundmass. If the rocks in the northernmost of the Courtland Hills are correctly correlated with the Sugarloaf, despite the absence of andesitic rocks in the type locality of that formation, the Bronco volcanics are more closely comparable. The andesitic breccias of the Bronco are like those east of South Pass which have been classed above as pre-Bisbee(?). Both contain hornblende and plagioclase as phenocrysts, though hornblende is the more conspicuous and abundant in the eastern locality and plagioclase in the western. The plagioclase of the rocks near South Pass is all indeterminable, however; so that no comparison in the compositions of this critical mineral in the two localities is possible. On the whole, the differences between the two suites and the uncertainties of the associations in the eastern localities are such that it seems inadvisable to correlate the two volcanic series on the basis of the information at hand, especially as the rocks near South Pass seem to be more likely older than the Bisbee formation.

AGE

That the Bronco volcanics are prethrust is somewhat doubtful as they nowhere contact the fault. Furthermore, this age assignment demands that the isoclinal folding of the Bisbee formation (over which the volcanic rocks rest in pronounced unconformity) resulted from an orogeny older than the thrust faults. However, the trends in the isoclinal folds are nearly east, whereas the thrust seems to have travelled nearly eastward and they might well be products of different orogenies. The only evidence that the Bronco is prethrust consists of the intimate mixture of fragments of Bronco volcanics with sandstones of the Bisbee in the intrusive breccia of Uncle Sam porphyry west of Fairbank. This intrusive breccia is considered to have followed the thrust fault which would of course demand a prethrust age for all the clastic fragments involved in it. Although considerable suggestive evidence supports this interpretation (see p. 94–96), it can hardly be considered proved. The breccia may be wholly intrusive and independent of fault control.

The Upper Cretaceous rocks (Ross, 1925, p. 25–28, 50–51) of the Aravaipa–Stanley area to the north include andesitic volcanic rocks. In northern Sonora, about 40 miles south of this area, Taliaferro (1933, p. 12–37) has referred rhyolitic volcanic rocks to the Upper Cretaceous. In both areas the local thrust faulting is postvolcanic. In the Sonoran locality a mild unconformity intervenes between the Comanche and Upper Cretaceous, whereas no Comanche rocks have been recognized in the Aravaipa–Stanley area. On this rather feeble basis it is possible to justify assigning the Bronco volcanics to the Upper Cretaceous, but the parallelism in either structure, stratigraphy, or petrography between this area and either of the others referred to is not strong enough to be persuasive.

Paleogeographic considerations tend to oppose a Late Cretaceous age assignment. In Sonora to the south, the Patagonia area to the west, and Aravaipa–Stanley area to the north of the Tombstone area, the Upper Cretaceous is represented by marine and brackish water deposits of a sea that evidently had its shore to the south and west. It seems likely that marine Upper Cretaceous rocks were also deposited here.

If so, they were probably removed during and following the deformation recorded by the unconformity between Bisbee and Bronco rocks. This interpretation would put the Bronco volcanics in the early Tertiary. I think it fruitless to make a decision, which would be wholly subjective, between these possibilities on the evidence available.

COURTLAND-GLEESON AREA

SUGARLOAF QUARTZ LATITE

NAME

Sugarloaf quartz latite is so named because rocks of this formation are well exposed at Sugarloaf Hill, about a mile southeast of Gleeson.

Rocks of diverse origin and ages have probably been included in this formation as it is mapped on plate 5. In much of this area the rocks have been highly altered by hydrothermal solutions—locally so intensely as almost to destroy their diagnostic features. In mapping, an attempt was made to separate the rocks here considered as a single unit into two formations, but microscopic study has led to their assignment to a single one. The question is confused by the presence of dikes of a felsite which in altered condition strongly resembles the Sugarloaf quartz latite. These dikes, which are too small to map, are definitely intrusive, and the failure to discriminate them from some of the altered facies of the Sugarloaf quartz latite led to the preliminary interpretation that the whole formation, as represented at Courtland, was intrusive. The geological relations as a whole do not support this, and microscopic examination of specimens, despite their alteration, reveals some signs of a pyroclastic origin for parts of the formation.

On Turquoise Ridge these rocks have been mapped as quartz monzonite porphyry by Ransome (1913, p. 128–129) and Wilson (1927, p. 24). In all specimens examined, however, the rocks are entirely aphanitic in the groundmass, and the sporadic phenocrysts are also very small, so that it appears misleading to apply a name that connotes an intrusive origin and a coarser texture than the rocks possess. Furthermore, in rocks megascopically indistinguishable from these, and from nearby outcrops, traces of an original pyroclastic texture can be recognized. Accordingly, the whole mass is regarded as a volcanic unit, especially as the geologic relations are also such as to favor this assignment.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The largest exposure of the Sugarloaf quartz latite, and the least altered facies of it, is at the type locality, southeast of Gleeson. East and north of Sugarloaf Hill, quartz latite is sporadically exposed in many small blocks in the intimately thrust-faulted area that extends to the north end of the Courtland Hills. Few of these blocks exceed 5 acres in extent: the largest are the two at the southeast foot of Turqouise Ridge already mentioned as having been mapped as quartz monzonite porphyry by Ransome and Wilson.

Generally the Sugarloaf quartz latite is a relatively resistant rock and forms topographic prominences. Outcrops are less bold than those of the Bolsa quartzite and the more massive of the limestone formations but are far better than those of the coarser intrusive rocks and the Cretaceous sedimentary rocks.

GEOLOGICAL RELATIONS

The geological relations of the Sugarloaf quartz latite are somewhat ambiguous, owing both to the structural complexities of the area and the highly altered condition of much of the rock and of those associated with it in the mining areas. Except for the doubtfully identified bodies in the most northerly of the Courtland Hills (SW¼ sec. 9, T. 19 S., R. 25 E.), which may, indeed, correlate with the Pearce volcanics rather than with this formation, no exposure of a depositional base of the formation occurs in the area of plate 5. Nearly all the contacts with other formations are faults. Some contacts on the east slope of Turquoise Ridge are apparently unfaulted dike boundaries. However, even these are not conclusive as to an intrusive origin for the formation as a whole, because they may be dikes of a younger felsite that has been so altered as to be practically indistinguishable megascopically from the main mass of the formation. Such dikes do exist in exposures west of the old Great Western mine at Courtland, where a dike of felsite that is almost indistinguishable from the Sugarloaf quartz latite can be seen to cut both the quartz latite and the adjoining Abrigo limestone, as well as the horizontal fault that there separates the two. Incidentally, in this locality the Abrigo limestone is distinguishable with difficulty from the Sugarloaf quartz latite, as was noted previously by both Ransome and Wilson. The quartz latite is clearly older than the main period of thrust faulting that has affected the area, for it occurs as a constituent of the breccias and as slivers along the faults in many places; the ligthologically very similar dike just mentioned is equally clearly younger than the faulting. In view of this relationship the few dikelike masses of felsite that resemble this formation are not regarded as demonstrating an intrusive origin of the Sugarload quartz latite. The rocks referred to this formation at the type locality and southeast of Gleeson in general are clearly volcanic, with many definitely pyroclastic interbeds. In the mineralized areas nearer to Gleeson and in the Courtland district, the rock is so highly altered as to render uncertain its identity with that at Sugarloaf Hill. Nevertheless, even in these areas, relicts of a few structures that suggest shards are recognizable, and the rock is everywhere either entirely aphanitic or with an aphanitic groundmass and only small phenocrysts. These characters, occurring throughout areas as much as 2,000 feet across, make an intrusive origin appear highly doubtful; and accordingly, these more highly altered bodies are regarded as representative of the definitely volcanic formation so well exposed at Sugarloaf Hill. On the other hand, it must be admitted that such suggestions of a volcanic origin cannot be found throughout the formation as mapped, and more than one rock type may have been included under this symbol.

Most of the fault boundaries are low-angle thrusts, and there can be no doubt that the formation antedates the period of major thrusting. That it rests unconformably on the Bisbee formation follows directly if the rocks in the most northerly of the Courtland Hills have been correctly identified as belonging to this unit, for they rest on the Cretaceous. This is unfortunately not quite certain because of the considerable similarity of the rocks of these northerly localities with the S O and Pearce volcanics, both of which are believed to be of postthrust age.

At Sugarloaf Hill the bedding in the volcanic rocks dips rather uniformly about 30° to 35° ENE. The lower beds contain considerable foreign inclusions such as felsophyric andesite, limestone, mudstone, and quartzite. Some of these beds are pyroclastic; others appear to represent flows that picked up the inclusions either in the volcanic throat or in running over the surface. Higher in the section the numbers of these inclusions diminish, and the flows are more uniform. At the southeast end of the hill a porphyritic basalt flow apparently overlies or interfingers with the quartz latite. No representatives of this flow have been seen to the north, although its strike apparently should carry it into the dip slope of the northern part of the hill. Its absence there may be due to faulting.

An estimate of the thickness of the formation exposed in Sugarloaf Hill, based on the average attitude of the formation and the width of its outcrop, is about 1,500 feet. Although nowhere exposed, the contact with the Gleeson quartz monzonite to the west is believed to be a fault; the eastern contact, though concealed by alluvium, is also faulted. Accordingly, a complete section of the formation would be still thicker. At no other point in the area is a thickness of more than 500 feet exposed, and by far the larger number of masses referred to this formation show so few dependable primary structures as to prevent any estimates for them.

PETROGRAPHY

In the relatively fresh exposures, the Sugarloaf quartz latite is a light pinkish gray to pink rock that weathers brown and tan. Both at Sugarloaf Hill and the northernmost of the Courtland Hills, the rock shows phenocrysts of biotite (mottled brown and green), quartz, and chalky feldspar that range up to 2 millimeters and average 1 millimeter in length. The groundmass is aphanitic.

Microscopic examination reveals that the rock contains abundant crystals of plagioclase, most of which are altered to aggregates of clay minerals, but with sporadic grains identifiable as andesine (An_{35}). Quartz shows rounded and resorbed forms, though some grains are bipyramidal. Biotite occurs as books, many altered to chlorite and muscovite. Some specimens show sparse phenocrysts of sanidine, but most have their potassic feldspar represented by microcrystalline intergrowths with quartz in the groundmass, or by spherulitic aggregates about the phenocrysts. Epidote and chlorite are abundant in most specimens along with the clay minerals. Unusually stout and stumpy crystals of apatite are the most abundant accessories, along with magnetite, leucoxene, and a little zircon.

A few specimens show definite shard structures, but most of the pyroclastic parts are crystalvitric tuffs.

In the mineralized areas near Gleeson and Courtland, the rocks referred to this formation are generally light gray or dense white, with a slightly pinkish-gray hue on fresh fractures. Joints are stained with manganese dendrites or with iron oxides and appear pinkish tan to light gray in outcrops. The same phenocrysts are recognizable here as in the less-altered specimens, but the groundmass is commonly porcelaneous to chalky. In many exposures the rocks are much pitted, owing to the weathering out of pyrite cubes; and in some places on the east slope of Turquoise Ridge, where both rocks have been highly sericitized, the quartz latite is distinguishable from the altered Abrigo limestone only by close examination and even then with some uncertainty.

Under the microscope these highly altered facies are seen to be silicified and sericitized. Some show euhedral outlines of plagioclase, now bounding aggregates of epidote, clinozoisite or sericite in an albitic base; but none of the original plagioclase has been found in the many specimens examined from this area. No identifiable phenocrysts of potash feldspar occur, and the original biotite is completely altered to chlorite and muscovite. In many of the more sericitic specimens the alteration has proceeded so far that only crudely angular aggregates composed of mats of sericite are found in place of the sharply-bounded saussurite of the less-altered specimens. Some specimens contain only

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quartz phenocrysts, perhaps because any feldspar originally present has been replaced by sericitic aggregates that are so irregular in outline as no longer to permit the original minerals to be recognized.

The groundmass is microcrystalline and in many specimens suggests a devitrified texture, but this interpretation has not been safely established. It contains quartz, albite, and orthoclase, along with sericite, chlorite, calcite, and the accessories apatite, zircon, and magnetite. Leucoxene is also present in small amounts. Commonly the rock is veined with quartz that shows a comb structure.

Among the peculiarities of the rock, aside from the intense alteration that it has undergone, are the rounded resorbed crystals of quartz that occur as phenocrysts. Even in the least sericitic specimens in the altered mass of Turquoise Hill, these crystals are commonly surrounded by coronas of quartz-orthoclase intergrowths that are as much as 0.25 millimeter thick. These coronas blend with the groundmass and give a pattern reminiscent of secondary enlargement around quartz crystals in an ordinary quartzite. In specimens taken from near the contact with the Turquoise granite, the round grains of quartz poikilitically enclose minute plates of feldspar that are presumably orthoclase. These feldspar crystals are arranged tangentially around the cores of the quartz crystals but are completely embedded in the peripheral quartz, which is in optical continuity with the core. This feature is interpreted to be due to contact alteration of the quartz latite. Although the Turquoise granite may actually be younger than the Sugarloaf, even though it has been considered pre-Cretaceous above (p.67), this alteration seems more likely to be attributed to one of the felsite dikes than to the nearby Turquoise granite. Both the invaded and the intrusive rock have later undergone intense sericitization.

CLASSIFICATION

The classification of the fresher specimens of the rock, from Sugarloaf Hill, offers no difficulty. These are clearly quartz latite, having quartz, andesine, and biotite as phenocrysts, and even the specimens with no individualized sanidine have enough suggestions of potash feldspar in the groundmass to warrant this assignment. On the other hand, the question is not so clear in the rocks from Turquoise Ridge that were called monzonite porphyry by Ransome and Wilson but are here regarded as more probably part of the Sugarloaf quartz latite. The sparse phenocrysts and the resorption of the quartz crystals suggest a volcanic rather than an intrusive origin, as does also the wide extent of such a fine-grained and possibly devitrified rock. It is not impossible, however, that this mass may be hypabyssal and have been emplaced as one or more very viscous near-surface intrusions, as implied if the few apparently intrusive contacts with the Cambrian rocks are not all those of later dikes, as at least one is known to be. The rock is so highly altered that the composition of the original plagioclase it contained cannot be estimated. However, plagioclase is the only feldspar recognized among the phenocrysts, whereas both plagioclase and orthoclase occur in the groundmass. The abundance of sericite makes dependable estimates of the relative abundance of the feldspars difficult or impossible, but the fact that biotite was obviously the only original mafic mineral of the rock and that plagioclase was the only phenocrystic feldspar renders it probable that the rock has the composition of a quartz latite. The resemblance of the rock to the biotite-quartz latite of Sugarloaf Hill seems as strong as could be expected in view of the alteration that it has undergone. If the "ghosts" interpreted as shards have been correctly diagnosed it is practically certain that the altered facies is part of the same formation as the quartz latite of Sugarloaf Hill.

BASALT ASSOCIATED WITH SUGARLOAF QUARTZ LATITE

Porphyritic basalt in one or more flows occupies an area about half a mile long and 1,000 feet wide in the widest part along the southeastern slope of Sugarloaf Hill. The rock is quite different from any other found in the course of this survey; and because confined to this area, where all contacts with other rocks are concealed by alluvium, its relations are uncertain. The rock is trachytoid, and if the flow planes mark the attitude of the flow, as seems likely, it is essentially conformable to the Sugarloaf quartz latite to the west. However, the flow planes seem to steepen along the western contact, and both the basalt and the quartz latite to the west seem to be notably redder along the alluvium which separates the two bedrock masses. These features suggest that the contact that is here concealed by alluvium is a fault, a suggestion strengthened by the failure of the basalt to appear on the eastern spur of Sugarloaf Hill to the north, where projection of its attitude would carry it. Accordingly, the apparent conformity of the basalt and quartz latite may be illusory; the two rocks may be greatly different in age and history. Nevertheless, the basalt seems more appropriately discussed here than in connection with other basaltic bodies in the area, for these are composed of markedly different rock, and their relations, so far as known, seem not to throw any light on those of this porphyritic basalt.

The porphyritic basalt is about 300 feet thick, measured normal to the flow structure. It is uncertain whether this thickness represents one or several flow units. The rock is reddish gray, weathering to dark brown. Abundant phenocrysts of plagioclase which range up to an inch in length and breadth and one-fourth inch in thickness and much smaller phenocrysts of pyroxene are the only minerals recognizable in hand specimens. The groundmass is aphanitic. Under the microscope the feldspar is identifiable as calcic labradorite (An_{70}) and the pyroxene as augite. Magnetite is abundant in the groundmass, which also contains small crystals of plagioclase, augite, and accessory apatite, in a glassy base. The texture is intersertal. Some specimens have been considerably altered, with the formation of calcite, sericite, and chlorite. No signs of cataclastic deformation were noted; their absence cannot, however, be regarded as strong evidence that the basalt is younger than the thrusting, as it is a more massive and probably much stronger rock than the associated Sugarloaf quartz latite.

NORTHERN DRAGOON MOUNTAINS AND SULPHUR SPRING VALLEY AREA

GRANITE GNEISS NEAR JORDAN AND FOURR CANYONS

DISTRIBUTION

At the mouth of Jordan Canyon, near the northeast corner of the Benson quadrangle, a small mass of granitic rock clearly invades the Pinal schist. Several smaller bodies of similar rock also cutting Pinal occur to the south in the higher parts of Jordan Canyon. But toward the southwest, on the eastern slopes of the mountain spur that reaches an altitude of 6,541 feet, in sec. 7, T. 17 S., R. 23 E., similar rocks invade the Bisbee formation. The fault blocks of granite gneiss on the south slopes of this peak and further south, on the south side of Fourr Canyon, near its mouth, very probably represent the same intrusion, but the boundaries of these bodies with the Bisbee formation are all faults. These rocks resemble the ones to the north sufficiently, however, to justify their tentative correlation. The most southerly occurrence of this granite is in the valley about 1½ miles southwest of the Fourr Ranch house.

GEOLOGICAL RELATIONS

At the mouth of Jordan Canyon the intrusion cuts only older rocks, but the eastern contact of the small body about a mile farther south on the east slope of the 6,541-foot peak is definitely intrusive into the Bisbee. The western contacts of both these bodies is a fault along which the rocks have been highly brecciated and locally reduced to mylonite. (See plate 5.) This is the eastern of two rather definite and nearly parallel northward-trending faults that bound a sliver of gneissoid granite and subordinate amounts of other rocks. This sliver is about 1½ miles long and ranges between a few score and about 1,000 feet in width. The rocks within the sliver are highly sheared and broken, though in parts of the mass the displacement of adjacent blocks on the two sides of a shear surface is not enough to destroy minor dikes. Most of the sliver is gneissoid granite, and nearly the whole is so mapped on plate 5.

This sliver is cut off at the south by an eastward-trending fault. A mass of similar rock just to the southwest may represent the southern continuation, but it is not so much broken up as the northward-trending sliver just described. Still farther southwest, in the north part of sec. 24, T. 17 S., R. 22 E., a small mass of crushed granite crops out from beneath a flat thrust fault overridden by rocks belonging to the Bisbee, Horquilla, and Pinal.

The faults that have affected these granite bodies are regarded as belonging to the same epoch of deformation as the main Dragoon thrust faulting. They are certainly post-Bisbee and are older than the Stronghold granite, for small undeformed masses of the Stronghold granite occur directly on the strike of the northward-trending fault sliver, at the north base of the 6,541-foot peak. Furthermore, the granite breccia involved in the faulting has in part been remetamorphosed, presumably by the same intrusion. Accordingly the gneissoid granite in question is either Late Cretaceous or early Tertiary in age. Possibly it is the subsurface correlative of one or more of the post-Comanche-prethrusting volcanic series of the region.

PETROGRAPHY

The outcrops of the least-deformed parts of this gneissoid granite are somewhat mottled greenish to pinkish gray and spangled with splendant crystals of biotite. In the more deformed parts of the masses the dark minerals are much less abundant, and the rocks are alaskitic or aplitic appearing, light to pale pinkish gray, with only minor amounts of biotite. The grain size ranges greatly, obviously depending on the degree of brecciation of the rocks. Microcline crystals as much as 2 centimeters across occur, but many of these are broken. The average grain size of the quartz and microcline is perhaps 3 millimeters. Muscovite is present in all specimens examined. Biotite is present as streaks along fracture surfaces and as small individual flakes in the mass of the rock. No plagioclase is recognizable megascopically, and most of the rock contains very little.

In thin sections, microcline and quartz are seen to be the major constituents in all facies of the rock. Plagioclase only locally makes up as much as 10 percent of the rock, and it is all saussuritic, though in many specimens the sericite has grown into fairly large crystals of muscovite and left a water-clear albite base readily identifiable.

In the rocks from the body on the slopes of Fourr Canyon, biotite is conspicuous, both because of its relative abundance (which amounts to perhaps 5 percent or even more) and its strong pleochroism in green. It 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. Such rocks show suggestions of a granulitic texture. A little epidote is present in veins that cut all other minerals. Apatite, magnetite, and sphene are minor accessories.

The rocks are all somewhat cataclastic. In the rocks that carry notably larger quantities of biotite, the evidences of granulitic texture are relatively abundant; but in the more alaskitic- or aplitic-appearing specimens, there is relatively more brecciation. Apparently some movement occurred even during the remetamorphism of the granite, if this history has been correctly interpreted. Probably the range in proportions of dark minerals from place to place in these bodies is, as in the Gleeson quartz monzonite, a result of partial leaching out of the dark minerals in zones of greatest crushing. Although some specimens are true mylonites, most of the rock is best characterized as crystalloblastic-cataclastic biotite granite gneiss.

GRANITE IN ASH CREEK RIDGE

In the center of sec. 14, T. 18 S., R. 26 E., near the east boundary of the mapped area, a body of granite is exposed over an area of a few acres. It definitely invades the Bisbee formation.

This rock is pink, and weathers to a dark red brown. In hand specimens it appears somewhat brecciated, but this may be due to weathering, as the outcrops are near the level of the alluvium of the Sulphur Springs Valley. Quartz, microcline, biotite, and subordinate plagioclase are identifiable with the hand lens. The grains range from about 1 to 3 millimeters in diameter. Although specimens available were too friable to section, the rock is very likely a true granite, in spite of the possibility that there may be more plagioclase than is apparent in hand specimens.

This granite belongs to the same intrusive epoch as the granite near Fourr and Jordan Canyons about 20 miles to the northwest, though the possibility that it is related to the Stronghold granite cannot be eliminated, as its brecciation might be due to normal, rather than to thrust faulting.

INTRUSIVE ROCKS YOUNGER THAN THRUST FAULTS

UNCLE SAM PORPHYRY

NAME

The Uncle Sam porphyry was so named by Butler, Wilson, and Rasor (1938, p. 24) because it crops out on Uncle Sam Hill, about 2½ miles southwest of Tombstone. They recognized the rock as an intrusive quartz latite porphyry. Ransome (Jones and Ransome, 1920, p. 102, pl. 5) called the rock "rhyolite porphyry" but also regarded it as intrusive. Church (1903, p. 11–12) referred to the rock as a rhyolite flow. The rock is clearly intrusive at several contacts and has the composition of a quartz latite, so that the name and interpretation adopted by Butler, Wilson, and Rasor is here followed.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The principal outcrops of the Uncle Sam porphyry are on Uncle Sam Hill, The Three Brothers hills and nearby. Small dikes cut the Paleozoic rocks southeast of Ajax Hill; other bodies are in the hills near Charleston and southeast of Brookline, west of the San Pedro River. Small bodies occur near the river farther north, near the abandoned mill site of Contention, and others in the hills north of Boquillas.

The Uncle Sam porphyry is relatively resistant and stands in rather conspicuous craggy, rugged hills, above the broad valley pediments. The subdued topography on the formation west of the river is probably due in part to structure and only in part to the nearness of the main drainage course of the area.

GEOLOGICAL RELATIONS

The Uncle Sam porphyry invades the Bronco volcanics, Bisbee formation, and locally the Colina limestone and Epitaph dolomite at the exposed surface. At Bronco Hill and a point about 1½ miles to the southeast, it is cut by the Schieffelin granodiorite, but elsewhere its only contacts with younger rocks are with the valley fill of the San Pedro trough, which rests unconformably upon the eroded surface of the porphyry.

The contact relations of the porphyry are highly variable. At the north spur of The Three Brothers hills, west of Tombstone, the lower contact dips steeply southwestward, beneath the porphyry. Here the porphyry is in contact with the Colina limestone, which rests on a thrust fault that cuts the underlying Bisbee formation. Just to the southeast the Bisbee formation on the footwall of the thrust fault forms the country rock of the porphyry. From a point near the northwest corner of sec. 9, T. 20 S., R. 22 E., to the valley passing just southeast of the center of the same section, the wall rock is a breccia mass composed of blocks of limestone derived from the Naco group and conglomerate, sandstone, and mudstone from the Bisbee formation. None of these sedimentary blocks can be followed along the strike for more than a few hundred feet; all are thoroughly shattered and brecciated internally. Generally the fragments of Paleozoic rocks are more abundant near the contact, and those of the Bisbee formation preponderate farther northeast. The breccia is generally sheared, and many of the stronger shears dip westward about 35°, roughly paralleling the contact with the overlying porphyry. These relations strongly suggest that the porphyry occupies a thrust plane in at least this part of its outcrop.

North of Uncle Sam Hill a deep embayment in the contact between the porphyry and the Bisbee formation, which forms the floor of the valley, suggests that the Bisbee underlies the porphyry at a comparatively shallow depth. Indeed, this has been shown by the workings of the State of Maine mine, which penetrate a considerable body of shale on the bottom level, at an elevation of about 4,300 feet (Butler, Wilson, and Rasor, 1938, p. 101). The floor at this part of the intrusion is therefore probably at a comparatively shallow depth, but farther southeast, near the Tombstone-Charleston road, the exposed contact becomes nearly vertical and cuts the bedding of the country rock at a high angle. Throughout the area between this road and the ridge extending north from Ajax Hill, the porphyry forms highly irregular masses that cut the Bisbee formation without regard to its bedding. A significant feature of this area is the mass of Uncle Sam porphyry following the major fault that farther north separates the Bisbee formation on the west from the Bolsa quartzite on the east. This fault was undoubtedly formed at the time of the major deformation of the Tombstone district. It had a minimum displacement of 5,000 feet and must extend to a considerable depth. The porphyry is frozen to both walls of this fault and has not been notably deformed since its emplacement, showing that the intrusion occurred after the major local orogeny.

In sec. 25, T. 20 S., R. 21 E., the contact of the main mass of porphyry and the quartz latite of the Bronco volcanics is steep and transects the volcanic rocks at a high angle, but on the 4,540-foot hill in sec. 36, T. 20 S., R. 21 E., the Uncle Sam porphyry seems to be laccolithic as the andesitic member of the Bronco volcanics crops out in a nearly complete ring around it. The same relations prevail in the mass just north of Charleston, though the andesite does not crop out. Here the quartz latite member of the Bronco volcanics dips away from the porphyry mass on all sides, again suggesting a laccolithic dome.

West of the San Pedro River few contacts of the porphyry are exposed, except those with the late Tertiary and Quaternary sedimentary rocks of the valley fill. However, at the south end of the hills southeast of Brookline, the porphyry is in contact with the andesites of the Bronco volcanics. Here the andesite seems to be a conformable sheet between two masses of the Uncle Sam porphyry, or, stated in another way, the porphyry seems to form two sills separated by a thin septum of andesite. (See pl. 6, sec. *XXI–XXI′*.) Both the bottom of the upper sill and the top of the lower, as well as the internal structures of the porphyry, appear conformable with the bedding of the andesite. The narrow band of Bronco volcanics along the east side of the porphyry mass in SE¼ sec. 30, T. 20 S., R. 21 E., may be the footwall of the lower sill, but the actual contact is concealed. The mass of andesite in NW¼ sec. 20, T. 20 S., R. 21 E., appears to be an inclusion in the Uncle Sam porphyry, though it is possibly a part of the roof of the sill, if the sill form is maintained so far northward.

The Uncle Sam porphyry along the Babocomari River 2 miles northeast of Brookline seems to rest in essential conformity upon the Bronco volcanics. However, it can hardly be interpreted as the base of a sill, because the porphyry cuts across the bedding along the south side of the andesite breccia and the eastern contact dips eastward at about 35°, at a high angle to the bedding, with the porphyry overlying the andesite. This contact has been followed by a fault, but the fault displacement cannot have been great, as there are many narrow dikes of porphyry in the andesite and many large boulders of andesite included in the porphyry close to the contact. The mass of andesite breccia of the Bronco that crops out half a mile farther east along the Babocomari River is definitely an inclusion, for its contacts are all steep and irregular and many dikes of the porphyry cut the andesite.

The Uncle Sam porphyry that crops out near the San Pedro River between Fairbanks and Contention apparently forms two intrusive sheets which conform only in the most general way with the structure of the associated Bronco volcanics. Many small faults confuse the relations here, and many of the critical localities are concealed by the Tertiary and Quaternary deposits, so that the structural relations are obscure, but there are innumerable narrow sills of the porphyry along the bedding of the tuffs of the Bronco volcanics and considerable bodies of intrusive breccia, in which the fragments of tuff are strung out and bent by the viscous flow of the injected porphyry.

In the hills about 2 miles north of Boquillas, the Uncle Sam porphyry forms roughly sill-like masses that conform in general structure to the major folds, though they transect the second-order folds of the associated Epitaph dolomite.

INTRUSIVE BRECCIA

Two areas of intrusive breccia are associated with the Uncle Sam porphyry near the Babocomari River, one in sec. 8, T. 20 S., R. 21 E., and the other in sec. 17, about a mile farther south. At the northern locality an intrusive breccia occupies about 100 acres and is exposed in a topographic amphitheater, drained by an eastward-flowing stream. The breccia is fairly well exposed in the streambed and canyon walls. It consists of a jumble of rock fragments that range from more than 100 feet in diameter down to microscopic sizes. Some of these fragments are angular, but most are rounded on the edges. They are held in a matrix of Uncle Sam porphyry. Among the rocks included in the breccia, representatives can be recognized of the andesite of the Bronco volcanics, both flows and breccias, sandstone, mudstone, and conglomerate of the Bisbee formation, Epitaph dolomite, and Colina limestone. These rocks are arranged in a heterogeneous manner: limestone against andesite breccia, sandstone against conglomerate, dolomite against mudstone. The bedding of the blocks are at all attitudes: in some it is vertical, in others, perhaps alongside, it is horizontal or at any angle between. They are separated from each other by dikes and layers of Uncle Sam porphyry that range in thickness from a fraction of an inch up to several feet. All of these dikes and sills show prominent flow structures and are packed with even more inclusions than are normally contained in the porphyry. There seems to be a slight tendency for the more continuous sheets of the porphyry to lie at low angles and to dip away from the center of the mass in all directions. The normal porphyry overlying the breccia is almost surely domed over the breccia outctop, as the rather definite boundary of the breccia dips away from the center of the exposure at angles of 10° to 20°. On this interpretation of the structure, a thickness of about 100 feet of the intrusive breccia is exposed here, with no bottom visible. A dike of andesite porphyry cuts across breccia and porphyry and is clearly younger than both. It is probably not genetically related to these rocks.

Toward the east of this area of breccia is an unbroken block of andesite of the Bronco volcanics. It is likewise capped by a low dome (at least in the north-south section) of Uncle Sam porphyry. At its south edge an apparently vertical mass of Uncle Sam porphyry about 100 feet wide separates this unbroken body of andesite from a smaller mass of breccia like that to the west. The flow banding in the porphyry overlying the andesite along the creek southeast of the breccia area dips about 50° S., but this steep dip is apparently local and may be due to faulting. Measured normal to the flow structures, at least 300 feet of porphyry is exposed above the breccia.

The mass of intrusive breccia exposed to the south, in sec. 20, crops out in a subcircular area of about 70 acres. Here a breccia of sandstone, shale, and mudstone, probably derived from the Bisbee formation, is intimately cut by innumerable dikes and stringers of Uncle Sam porphyry that trend without apparent system in all directions. The porphyry stringers and dikes range from a few inches up to 50 feet in width. They show strong flow structures and are packed with inclusions of sandstone, shale, conglomerate, rhyolite, and a white granitoid rock of unknown source. Some of the inclusions are as much as 4 feet long, but most of them measure only a fraction of an inch in length. Here, again, the overlying, less-contaminated porphyry appears to be domed over the breccia, though the exposures are not quite good enough to prove this.

INCLUSIONS

Some of the larger inclusions have been described in connection with the geological relations of the porphyry, as have the masses of intrusive breccia. However, inclusions are by no means confined either to these occurrences or to the border zones of the porphyry and are found in great profusion almost everywhere in the mass. They exhibit a great range in size. The largest noted outside of the breccias was 20 by 40 feet; many are as much as 5 feet across, but the bulk of them are between a small fraction of an inch and an inch in diameter. They are so abundant in nearly all exposures that an ordinary hand specimen commonly shows at least one and may show half a dozen such inclusions on its surface. This is true not only near observed contacts where inclusions are commonly more abundant than elsewhere but also far from any known contacts; for example, along the west slopes of the Tombstone Hills and east of Brookline, half a mile or more from the nearest outcrops of country rocks. In places the inclusions are so numerous that the porphyry verges on a breccia.

In the areas west of the San Pedro River, most of the inclusions are andesite and quartz latite of the Bronco volcanics, though sandstone, shale, and mudstone from the Bisbee formation are also abundant and a few fragments of granitic rock occur. In the areas east of the river, inclusions of volcanic and Bisbee rocks are abundant, but quartzite, dolomite, and limestone of Paleozoic age and Pinal schist can also be recognized. Also found are fragments of granitic rock like that west of the river, where they do not seem so plentiful as here. Near the contacts the inclusions of the adjacent rock definitely tend to preponderate, but even here there are many representatives of other formations.

Most of the inclusions are angular and show abrupt boundaries with the porphyry matrix, but a few are round and in hand specimen appear to blend with the porphyry. Most of the inclusions of shale or mudstone are partly or wholly altered to hornfels, but the alteration of other rocks is far less conspicuous. Microscopic study shows, however, that many of the andesite inclusions have undergone slight alteration and, especially, mechanical disruption.

As mentioned before, the inclusions are generally, though not invariably, more abundant near the contacts than elsewhere. Locally such aggregations of inclusions preponderate greatly over the matrix, forming bands that differ notably from the main mass of the porphyry. At the south end of the hills southeast of Brookline such a layer of inclusion-rich porphyry is well developed at the base of the upper of the two sills there exposed. Here the upper part of the sill is eroded away and the topmost exposures are of the normal Uncle Sam porphyry that contains many small inclusions. Toward the base the number and size of the inclusions increases, and a layer about 30 feet thick consists of perhaps 10 percent inclusions. This layer weathers into peculiar nodular outcrops. The nodules range from a few inches to about 3 feet in diameter, and the center of each is formed by an inclusion. Most of these inclusions are subrounded or subangular and consist of felsophyric hornblende andesite like that which underlies the sill. Around each of the inclusions, which range in diameter from an inch up to about a foot, the porphyry has a finer selvage and apparently has been quenched. The spheroidal weathering is partly a reflection of the smoothly flowing curves of the flow structure of the porphyry matrix, but this cannot account for the nearly perfectly spheroidal form of the weathered boulders. The round forms emphasized by the weathering look like piles of cannonballs or coarse rounded boulders and cobbles (Gilluly, 1945, p. 650, pls. 1, 2). This layer grades downward rather abruptly into a layer that consists overwhelmingly of inclusions—seemingly as much as 60 or 80 percent—and in which the strongly flow-streaked porphyry matrix hardly suffices to separate the inclusions but merely fills the interstices between them. This zone forms the base of the sill, and its contact dips gently westward in approximate conformity with the bedding of the underlying volcanic breccia.

Bands of similar "cannonballs" occur at several other places in the hills southeast of Brookline. In the north center of sec. 30, T. 20S., R. 21 E., such a band lies at the base of a porphyry sill, but in several other localities in secs. 18 and 19 of the same township the nodular-weathering bands are definitely not at the base of the sill, though they may be near the top, which has been eroded away

PETROGRAPHY

The Uncle Sam porphyry is gray to pinkish gray, but weathers to buff and rusty brown hues. The phenocrysts are inconspicuous on weathered surfaces, but plagioclase, biotite, and subordinate hornblende form crystals that range from about 1 to about 8 millimeters in length. Quartz generally forms somewhat smaller and fewer phenocrysts. The groundmass is aphanitic and near the contacts is commonly glassy. Still more surprising, in view of the size of the intrusive mass, is the occurrence of only partly devitrified facies hundreds of feet away from any exposed contacts. The inclusions, which are so abundant as almost to be characteristic of the mass, have been mentioned in the preceding section. They commonly have megascopically abrupt boundaries against the porphyry matrix, though some appear to blend into the porphyry and in many places dark clots in the porphyry suggest more completely digested inclusions. The microscope shows, however, that these apparently blending contacts are chiefly due to the mechanical strewing out of included material and not to reaction with the magma.

The microscope shows that the commonest facies of the porphyry contains phenocrysts of plagioclase, quartz, biotite, and hornblende, in a glassy base or a groundmass of quartz, orthoclase, plagioclase, and biotite. A few specimens contain orthoclase phenocrysts also; these are cryptoperthitic or definitely perthitic. Commonly the plagioclase is zoned from about An_{43} to An_{30}, but there are exceptional phenocrysts whose cores are near An_{50}. Among the inclusion-rich rocks there are notable variations from these compositions. Quartz is generally embayed, but some of it has modified rhombohedral forms. A few specimens of those studied contain no quartz phenocrysts. The biotite is the normal brown variety, but much of it has been altered to chlorite. Hornblende is present in but few of the specimens examined though perhaps half of them contain chlorite pseudomorphous after it. In the fresh specimens the hornblende is the common green variety, with extinction angles of 17°–18°.

A notable feature of the porphyry is the fracture (and strewing out of the resulting fragments) of a large proportion of the phenocrysts.

The groundmass ranges from vitric to microcrystalline, with a maximum grain size of about 0.04 millimeter, though more usually the groundmass crystals do not exceed 0.01 millimeter. Some specimens collected at points hundreds of feet from exposed contacts are partly glassy and contain microspherulites of orthoclase. Where determinable, the groundmass plagioclase is near An_{30} in composition and is contained, along with chlorite or biotite, in an intergrowth of orthoclase and quartz or glass.

Accessory minerals include magnetite, apatite, zircon, and sphene, but much of the sphene is a product of the alteration of biotite and presumable ilmenite. A few specimens contain rosettes of tourmaline, dichroic in greenish brown and brown. Many of the specimens are mildly altered, with sericite, epidote, and albite developed in the plagioclase crystals and the mafic minerals altered to chlorite. Calcite is also present in some of the rocks.

The above descriptions apply to most of the Uncle Sam porphyry, which generally contains abundant inclusions. In the small individual samples afforded by thin sections but few inclusions were seen. For this reason, several specimens from parts of the mass unusually rich in inclusions were selected for study. Several of these came from the Tombstone Hills, but most were from the hills west of the San Pedro River southeast of Brookline.

Most of the inclusions show microscopically sharp boundaries against the porphyry and little or no sign of reaction between the magma and inclusions. A cloudiness due to an indeterminable fine black dust in many of the feldspars is the only sign of alteration of the minerals of the inclusions. Inasmuch as most of the groundmass of the porphyry is either glassy or very finely crystalline, this lack of strong reaction is not surprising. Nevertheless, the mechanical inclusion of the foreign rocks and the strewing out of the fragments from them has produced considerable local variation in the composition of the porphyry. The inclusions of andesitic material, probably chiefly derived from the adjacent Bronco volcanics, are especially noteworthy. In several rocks containing such inclusions, small fragments apparently derived from larger ones are strewn out in flow patterns and thus represent a stage in the dispersion of xenocrysts through the porphyry. In order to investigate this and estimate the extent of the contamination, the plagioclase of the porphyry was especially studied.

Specimens of the porphyry that contain relatively few inclusions (none seen in the particular thin sections studied) show rather remarkably constant compositions of the plagioclase. Few crystals have cores more anorthitic than An_{45}, and An_{50} was the extreme noted. In 11 of these rocks the range was only from An_{35} to An_{30}. These determinations were made by immersion methods and examination of thin sections by ordinary methods. For study of the apparently contaminated rocks, it seemed desirable to resort to a means by which the composition of an individual crystal could be determined, and several such specimens were examined by universal-stage methods. The results of this work on individual plagioclase crystals are summarized in the following table.

Molecular percent anorthite of individual feldspar crystals in specimens of the Uncle Sam porphyry

[z, zoned crystal; i, crystal definitely part of an inclusion; g, crystal in glassy base]

Crystal	Specimen								
	125	255	256	260	261A	261D	283	286	287
1	32	35	50i	30i	50g	32g	39g	36g	33g
2	32	37	50i	31i	52g	32g	40i	38g	35g
3	32	37	52i	30–22zi	52g	36g	40g	38g	35g
4	32	37	52i	37–8zi	54–42zg	38g	40g	38g	36g
5		37	54i	25±4i	55g	38g	40±5i	39g	37g
6		38	55i	37–20zi	58g	45i	40±5i	40g	38g
7		38	55–45zi	47–8zi	58g	55i	41i	40g	39g
8		38		36g	60g	55i	41g	40g	
9		38½		36g	65–56zg	55i	43g	50g	
10		39		38g	67g	56i		50g	
11		43?		38g	70–60zg	58i			
Mean (inclusions)			52	27		56	40		
Mean (porphyry)	32	38		37	57	35	40	41	36

Of the above specimens, nos. 125 and 255 contain no identifiable inclusions; no. 256 is an andesite fragment included in no. 255; no. 260 is porphyry with a glassy groundmass that contains an inclusion of granitoid rock, the feldspars of which have the compositions indicated; no. 261A is largely devitrified andesite in fragments separated by stringers of highly fluidal glass containing feldspars essentially identical with those of the andesite and interpreted as xenocrysts freed from the inclusion; no. 261D, which is part of the same intrusive breccia as no. 261A, consists of andesite inclusions in more abundant glassy porphyry; no. 283 is glassy porphyry containing inclusions of quartz latite (Bronco?); nos. 286 and 287 contain inclusions chiefly of shale, and no feldspars are identifiable. It is somewhat surprising to find that the feldspars in the glassy matrix of no. 261A are wholly those of the andesite inclusions; for aside from this specimen, the plagioclase of the porphyry is more albitic, even in the glassy facies. Accordingly, one would expect some of the indigenous feldspar of a composition near An_{40-30} to be intermingled with the xenocrysts derived from the andesite, especially as such feldspars are found in the neighboring specimen, no. 261D. Possibly the absence of these primary feldspars from the narrow glassy seams that separate the fragments of andesite in this specimen is due to the constricted passages between the fragments, which perhaps strained out the larger feldspars in the porphyry magma. This explanation seems a bit farfetched, but no other occurs to me.

It is perhaps significant that all the specimens listed in the table are glassy except for nos. 125 and 255. The constancy of the composition of the feldspars of these glassy rocks—ranging between An_{43} and An_{30}—is such as to render suspect the two crystals in no. 286 with an anorthite content of 50 percent. Perhaps these are xenocrysts from inclusions of andesite, some of which were seen in the neighboring rock. If so, the few crystals seen in the porphyry elsewhere, which have cores as calcic as An_{50}, are probably to be similarly interpreted. In these other rocks in which the groundmass is more largely crystalline, there should have been better opportunity for reaction between xenocrysts and magma than in the glassy facies, with correspondingly more chance for zoning around the nuclei of any xenocrysts that might be present. This, of course, is not a necessary interpretation of these more calcic cores, for the natural evolution of the magma would lead from the more anorthitic to the more albitic feldspars, and these cores may record an earlier intratelluric stage in the magmatic history. The uniformity of the feldspars in so many specimens, however, suggests that the porphyry magma is rather uniform as emplaced and hence that these more calcic cores may not represent intratelluric feldspars but xenocrysts.

CHEMICAL COMPOSITION

The following chemical analyses of the Uncle Sam porphyry shows that the rock is a quartz latite porphyry.

Chemical analyses of Uncle Sam porphyry

[Specimen data: 1, Quartz latite porphyry from a point about 1,500 feet northeast of Bronco Hill, in sec. 7, T. 21 S., R. 22 E., Lee C. Peck, analyst; 2, quartz latite porphyry from southernmost exposure on west side of San Pedro River, in sec. 25, T. 20 S., R. 20 E., Lee C. Peck, analyst; 3, quartz latite porphyry from a point 2½ miles west of Tombstone and ½ mile east of The Dome (Butler, Wilson, and Rasor, 1938, p. 25), R. C. Wells, analyst]

	1	2	3	Average
SiO_2	66.59	68.16	68.04	67.60
Al_2O_3	16.77	16.07	15.82	16.22
Fe_2O_3	1.94	1.75	2.34	2.01
FeO	1.26	1.15	.84	1.08
MgO	1.04	.90	.80	.91
CaO	2.86	2.61	3.26	2.91
Na_2O	3.66	3.79	3.93	3.79
K_2O	3.77	3.64	3.32	3.58
H_2O+	.98	1.01	.77	.92
H_2O	.21	.25	.37	.28
TiO_2	.38	.43	.42	.41
P_2O_5	.26	.16	.15	.19
MnO	.11	.11	.07	.10
ZrO_2	n. d.	n. d.	None	--------
CO_2	n. d.	n. d.	.04	--------
S	n. d.	n. d.	Tr.	--------
NiO	n. d.	n. d.	None	--------
BaO	n. d.	n. d.	.06	--------
SrO	n. d.	n. d.	.01	--------
Li_2O	n. d.	n. d.	Tr.	--------
Cu	n. d.	n. d.	Tr.	--------
Zn	n. d.	n. d.	None	--------
Total	99.83	100.03	100.24	100.00

Norms of Uncle Sam porphyry

Normative mineral	1	2	3
Quartz	23.88	25.98	24.60
Orthoclase	22.24	21.13	19.46
Albite	30.92	31.96	33.54
Anorthite	12.51	11.95	15.29
Corundum	2.14	1.63	.10
Hypersthene:			
en	2.60	2.20	2.00
fs	.26	.13	--------------
Magnetite	2.78	2.55	1.86
Ilmenite	.76	.76	.76
Hematite	----------	----------	.96
Apatite	.67	.34	.34
Symbol	1.4.2.3(4)	1.4.2.3(4)	1.4.2(3).(3)4.

INTERNAL STRUCTURAL FEATURES

Despite the abundance of inclusions and the prominence of biotite in the Uncle Sam porphyry, flow structures are only locally conspicuous and in many places are impossible to discover despite careful examination. The orientations of such structures as were observed are shown on plate 9; more careful and systematic examination than was possible during this study might give considerable additional data, but the widely variant attitudes seem to show clearly that the structural trends recorded by the foliation and by the alinement of inclusions do not correspond very closely to the contacts of the mass. This conclusion was reached also by Ingerson (1939, p. 615–620) after a more intensive study of the northeastern part of the mass in the Tombstone Hills. He stated—

> A glance at the projection shows that there is no significant preferred orientation of the platy inclusions. Even near the contacts there is slight tendency for inclusions to lie parallel to the contact surfaces, there being only 5 out of 21 inclusions measured near contacts that are within 20° of parallel to the contact surfaces. Two of the inclusions stand almost normal to the contacts and two others make angles of over 60°, the average being 40°.

He also pointed out that the joints measured in the same part of the intrusive are nearly randomly oriented in azimuth but that most dip steeply. Whether the scarcity of low-dipping joints is real or only apparent because of difficulties of measurement on gentle slopes is difficult to decide. At any rate, Ingerson shows that the available information on the joints does not suggest a shallow floor. Nevertheless, the area studied by Ingerson includes that near the State of Maine mine, in which both surface exposures and mine workings strongly suggest that the floor lies at a rather shallow depth. From this it may be concluded that locally such features as joints and inclusions are not reliable clues to either the proximity or attitude of the contacts.

In the hills southeast of Brookline the zones of inclusion-rich porphyry rather closely parallel the exposed contacts, and this also is the impression given in the area of the intrusive breccias north of the Babocomari River. In the western part of the intrusion, accordingly, a sill-like form is suggested both by internal structures and contacts.

EMPLACEMENT

The wide area of younger rocks that separates the main exposures of the porphyry on either side of the San Pedro River makes it uncertain whether these are parts of a single large body or of separate masses. Even if the masses west of the river form a separate intrusive, however, the problem of the emplacement of the porphyry is only slightly less puzzling. The solidification under cover—even a shallow cover—of a body of igneous rock several hundred and perhaps more than a thousand feet thick and at least 3 miles in diameter does not normally yield a microcrystalline to vitrophyric rock. How so large a mass could be so quickly quenched is difficult to understand.

That the magma was within its crystallization range when it was injected is clear from the uniform size and composition of the phenocrysts in both the glassy border facies and in the more largely crystalline phases. The notable fracturing of both inclusions and phenocrysts also suggests a highly viscous magma. How so viscous a magma could incorporate so large a proportion of inclusions and distribute them so nearly uniformly through its mass is also difficult to comprehend, as the possibility of turbulent flow seems remote.

These anomalous features of the Uncle Sam porphyry are probably connected with its mode of emplacement. It may be recalled that the northeast contact of the main mass in the Tombstone Hills is locally formed by a wide zone of overturned and brecciated beds belonging to the Bisbee formation and the Naco group, in which the Naco rests in part upon overturned beds of the Bisbee. The Naco is thrust over the Bisbee on a clean-cut fault at the north end of the Tombstone Hills, north of The Three Brothers hills. The contact along this side of the porphyry dips southwestward beneath the intrusion, and Bisbee strata are penetrated beneath it in the State of Maine mine. These relations suggest that the porphyry here occupies a thrust plane; unfortunately not enough of the other contacts are to be seen to establish whether or not this is so. It is clear that the intrusion of the porphyry did not itself cause the overturning of these beds and the thrust fault, because the intrusion is not deformed nor does it have systematic flow structures related to the contacts. This is also the conclusion of Ingerson (1939). Further evidence that the intrusion is younger than the major deformation of the region is furnished by the dike of Uncle Sam porphyry that occupies, with frozen contacts, one of the major normal faults of the Tombstone district just west of Ajax Hill. This fault is younger than most, if not all, of the folding in this area. Accordingly, it seems reasonable to attribute the relations just discussed to the occupation of a low-angle westward-dipping thrust fault by the porphyry.

If this is true the innumerable fragments incorporated in the porphyry need not be attributed to stoping, which would be decidedly unlikely for a magma so near its consolidation temperature at the time of emplacement, nor to abrasion of the walls of the conduit. The fragments may reasonably be regarded as breccia along the thrust fault, already comminuted and ready for engulfment when the magma occupied the fault space.

It is by no means intended to imply that the porphyry is confined to a thrust surface. At many places between the Tombstone-Charleston road and Ajax Hill, the porphyry occupies irregular dikes and cannot be governed in detail by a preexisting fault pattern. Similarly, near Bronco Hill and north of Lewis Springs the assumption of fault control would be gratuitous. However, in neither of these localities are the inclusions so abundant as they are in the main mass, and at least in the southern localities the groundmass of the porphyry is more coarsely crystalline than usual. Unfortunately, the possible significance of this feature was not realized at the time of the fieldwork, and collections were not sufficiently extensive to warrant any statement as to details of crystallinity of the minor masses west of Ajax Hill.

In the hills west of the San Pedro River, contacts with older rocks are even fewer than in the Tombstone Hills. That the intrusion is more or less sheetlike seems indicated by the local relations at the most southerly outcrops of these hills, but farther north no contacts with massive country rocks are found except northwest of Fairbank where the exposures are poor and far to the northwest near Boquillas. Near Boquillas the porphyry has a generally sill-like form, though it sends out a dike for several hundred feet into the wall rock, the Epitaph dolomite. No fault control of the intrusion is suggested in this northernmost exposure. The intrusive breccias east of Brookline, however, though not proving that the porphyry has here incorporated a thrust breccia, are certainly compatible with such an interpretation. The strong suggestion of a sheetlike form of the breccia and the apparent conformity of the structure of the porphyry above the largest of these masses, together with the intimate jumbling of blocks from very diverse stratigraphic positions, all fit very well with the view that the porphyry here, also, occupies a thrust plane. That such an assumption is compatible with the geologic history of the region is pointed out in the section on Structure, though there is no direct evidence, owing to the overlap of younger formations, that the thrust faults occur west of the San Pedro River.

A sheetlike form for the larger bodies of Uncle Sam porphyry seems a necessary corollary of its fine grain and even vitrophyric texture. If this sheetlike form is controlled by one or several preexisting fault surfaces, a reasonable explanation is afforded for the high content of inclusions of diverse origins. The possibility immediately arises that the inclusions may have contributed to the quick chilling of the intrusion. Although their incorporation would almost surely have chilled the magma, the quantity of incorporated material hardly seems enough to be effective, though no other likely mechanism can be suggested.

In order to evaluate the temperature effect of the inclusions on the magma, certain assumptions are necessary. These include estimates of the specific heat of inclusions and magma and of the original temperatures of inclusions and magma at the time of the incorporation. In view of all the uncertainties involved, only estimated values can be assigned to any of these factors. The specific heat of both magma and inclusions is assumed to be the same. (Daly, 1933, p. 63 234–235).[8] The temperature of the inclusions at the time they were incorporated in the magma can only be guessed at, but if they were picked up near the final resting place of the magma, they were probably not at great depth—perhaps 3,000 feet—and with a normal thermal gradient of 1°C per 100 feet and surface temperature of 20°C would have had a temperature not far from 50°C. The temperature of the magma may be assumed as 700°C, within the crystallization range of quartz latite magma as estimated by Larsen (1929, p. 94). These assumptions thus postulate a temperature difference between the magma and inclusions at the time of their immersion of 650°C. Inasmuch as the specific heats of the two can be regarded as the same, the final temperature of the mixture would be related to their initial temperatures inversely as the masses of the material involved.

Let x be the temperature increment of the inclusions, y the temperature decrement of the magma. Then, if the inclusions amount to 3 percent of the final mixture.

$$3x=97y$$
$$x+y=650°\mathrm{C}$$

The solution of these equations gives $y=19.5°\mathrm{C}$ as the temperature drop in the magma as a result of the chilling effect of the inclusions. If the inclusions are assumed to amount to 5 percent of the final rock—an improbably high figure for the mass as a whole—the magma would be cooled 32.5°C by their incorporation.

Although these calculations are very rough and based upon assumptions that may be considerably in error, it seems unlikely that the chilling effect of any reasonable amount of inclusions could have exceeded 50°C, and probably it was not more than half that. Little is known of the rates of crystallization of the rock-forming minerals and their variation with temperature, and it may be that a rapid chilling of even this moderate amount might suffice to preserve the glassy or extremely fine-grained groundmass that characterizes the porphyry. However, it seems that this would only be true if the magma as intruded were also unusual in some other respects. The unusual character must likely to have contributed in this way is poverty in fluxes, a poverty that is consistent with the insignificant reaction of the inclusions with the magma and with the slight contact alteration of the country rocks. Accordingly, the unusual fine grain of the groundmass of the Uncle Sam porphyry may be in part a result of the incorporation of the unusual amount of inclusions, but this was probably combined with a marked poverty in volatiles in the magma, perhaps because of their escape through fissures from this shallow mass. C. A. Anderson has suggested (oral communication, April 1952) that the bulk composition of the magma may have been close to the "eutectic" composition that would permit its temperature to fall unusually low before crystallization proceeded far. Thus the slight, chilling effect of the inclusions and a moderate loss of volatiles on intrusion might suffice to quench the magma.

ANDESITE PORPHYRY PLUG AND DIKES NEAR BRONCO HILL

GENERAL FEATURES AND DISTRIBUTION

Andesitic dikes, though nowhere abundant, are found at many places in the area. Most of them are too small to map on the scale employed and their relations were

[8] Daly's figures differ slightly for vitreous and solid phases, and the specific heats of both are functions of temperture, but as a rough approximation, identical specific heats may be assumed without serious error.

carefully studied only in localities where they seemed likely to give evidence of the mutual relations of the adjoining rocks. Even this cursory examination, however, sufficed to demonstrate that andesite porphyries of at least two ages are present. The casual study devoted to the dikes that occur in rocks older than the Schieffelin granodiorite and do not cut younger formations has been insufficient to justify separate discussion of most of them.

A plug-shaped body of andesite porphyry, about 1,000 by 1,000 feet in surface exposure, occurs about 1½ miles northeast of Bronco Hill. Dikes from this body cut the Bisbee formation, the Bronco volcanics, and the Uncle Sam porphyry. One dike is in turn cut off by the Schieffelin granodiorite, a fact that constitutes the only evidence recognized as showing the Uncle Sam to be older than the Schieffelin.

PETROGRAPHY

The andesite porphyry of the plug and associated dikes is a medium-gray rock with phenocrysts of chalky plagioclase, up to 6 millimeters long, and chloritic aggregates of about the same size that apparently represent original hornblende, in an aphanitic groundmass. The rock has been hydrothermally altered, and in thin section is seen to be composed of considerable epidote, sericite, chlorite, and calcite, with only residua of andesine-labradorite and magnetite representing its original minerals. The texture is pilotaxitic.

AGE

The rock of the plug and dikes resembles the andesite of the Bronco volcanics, but structural relations clearly show that it is considerably younger. On the other hand, it is older than the andesite porphyry dikes north of Comstock Hill, which cut the Schieffelin grandiorite.

SCHIEFFELIN GRANODIORITE

NAME

The intrusive rock exposed in the vicinity of Schieffelin's Monument, about a mile northwest of Tombstone, was named the Schieffelin granodiorite by Butler, Wilson, and Rasor (1938, p. 25). Although their own description ("about equal quantities of plagioclase, ranging from andesine to labradorite, and orthoclase, with quartz, etc.") suggests a quartz monzonite and the chemical composition is about intermediate between quartz monzonite and granodiorite, the average rock of the mass probably conforms better to accepted definitions of granodiorite than to those of quartz monzonite. Although the rock could nearly as well be called quartz monzonite, the name granodiorite is here retained because of the desire to distinguish it from the several quartz monzonites in this general area.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The principal area of outcrop of the Schieffelin granodiorite lies in the Tombstone district where it occupies an area of about 3 square miles, extending along the northeast slopes and forming the upper part of the dissected pediment bordering the Tombstone Hills. It doubtless underlies the alluvium for some distance north of Comstock Hill. A second mass forms Bronco Hill, underlies the lower surrounding country for an unknown distance, and possibly is continuous, beneath the valley fill, with the mass north of Lewis Springs. These two southern exposures aggregate about 1 square mile but doubtless may be regarded as representing a considerably larger body.

Except for Bronco Hill, the topography carved on the Schieffelin granodiorite is subdued, and the greater headward extent of the pediment along Tombstone Gulch than elsewhere along the north side of the Tombstone Hills shows that the granodiorite is less resistant to erosion under the existing conditions than most other bedrock formations. The rock generally breaks down to sand, leaving residual round masses that dot the surface and gradually crumble also to grains that can be transported on the available low gradients. The topographic prominence of Bronco Hill is exceptional and possibly due to lack of jointing or to local silicification, though no observations were made to test these possibilities. At any rate, the rest of the southern exposures are similar topographically to the northern.

GEOLOGICAL RELATIONS

Intrusive contacts of the Schieffelin granodiorite are found with all members of the Naco group and with the Bisbee formation, Bronco volcanics, and Uncle Sam porphyry. At the south end of the northern mass, the intrusion cuts across the steeply tilted beds of the Naco group, which are cut off to the west by a steep normal fault along which the Bisbee formation has been dropped against them. For nearly half a mile north of, and on the projected extension of this fault, the west boundary of the intrusion is remarkably regular and might, from the map, be regarded as a fault boundary. However, the contact alteration of the Bisbee formation along this line has been quite as intense as elsewhere at the contact of the intrusion and a few exposures of the contact showing the intrusion frozen tightly to the sedimentary rocks demonstrate that the boundary is intrusive, though it was probably localized by this preexisting large fault. In this northern area the granodiorite is not in contact with the Uncle Sam porphyry; and, though the porphyry also occupies the same fault to the south, there is here no evidence as to the relative ages of the two intrusions.

Along the northeast foot of Bronco Hill, the Schieffelin granodiorite is in contact with the Uncle Sam porphyry for more than 3,000 feet. No dike of either rock was found in the other. However, in the western part of sec. 7, T. 21 S., R. 22 E., a large dike of andesite porphyry cuts the Uncle Sam porphyry and is cut off cleanly by the Schieffelin granodiorite. This establishes the age of the Schieffelin as younger than the Uncle Sam. In the hills 1¾ miles due north of Lewis Springs, the Uncle Sam porphyry has been slightly altered along the contact of a mass mapped as Schieffelin, confirming the age sequence indicated by the relations of the dike. At this last locality, however, the petrographic character of the intrusion mapped as Schieffelin is somewhat different from that of the formation at other localities, and there may be some question about its correlation with the Schieffelin.

At all exposures of the Schieffelin granodiorite contacts it crosscuts its wall rocks cleanly, without disturbing the structural trends found in them away from the intrusion. That its horizontal extension at depth is greater than at the surface is strongly indicated along the northeast side of the Tombstone Hills, where the contact curves southwestward into every topographic depression for a considerable distance and must be inferred to dip at a low angle in this direction. West of the Lucky Cuss mine there is similar evidence of a southward-dipping contact, and downward widening of the mass is suggested at several other points in the mining district (Butler, Wilson, and Rasor, 1938, p. 26). This fact, in conjunction with the lack of disturbance of structural trends far across the intrusion (especially along the northeastern border), the clean-cut contacts, and absence of any suggestion of metasomatic emplacement, makes it seem very likely that the intrusion stoped its way into the position it now occupies. Exposures of the contacts of the southern mass, or masses, are too meager to permit any conclusions as to their manner of emplacement.

PETROGRAPHY

The Schieffelin granodiorite is light gray, and weathers buff. In hand specimens it is light greenish gray or pinkish gray and mildly porphyritic. Plagioclase in crystals that chiefly range from ½ to 4 millimeters but exceptionally reach 1 centimeter in length, hornblende, in prisms as much as 1 centimeter long, but chiefly much smaller, biotite, and quartz, each in grains about 1 millimeter in diameter, are recognizable with the hand lens. In some specimens orthoclase can be recognized; in others, its presence is suggested by the light pink of an aphanitic groundmass which is subordinate to the recognized minerals. Local facies of the intrusion along the contact west of Bronco Hill are dark gray and have abundant biotite, along with well-individualized orthoclase, but are otherwise similar to the main facies. The rock from the mass north of Lewis Springs is somewhat more strikingly porphyritic than the average, and no phenocrysts of quartz are present; it may represent a distinct intrusion but is here regarded as a somewhat aberrant facies of the Schieffelin.

In thin sections the Schieffelin granodiorite is seen to consist of 40–50 percent plagioclase, 5–15 percent quartz, 10–30 percent orthoclase, up to 2 percent augite, 3–10 percent hornblende, 3–8 percent biotite, accessory sphene, magnetite, apatite, and with a little chlorite, epidote, albite, and sericite. The plagioclase is zoned, with the cores of the crystals ranging between An_{60} and An_{45} and the mantles between An_{40} and An_{30}, although in certain extreme specimens the zoning extends as far as An_{10}. The average composition, however, must be considerably more anorthitic, perhaps near An_{40}. In some specimens the orthoclase is somewhat perthitic and forms crystals about 2 millimeters in diameter that constitute about 20 percent of the rock, but much of the potash feldspar forms a micrographic groundmass with the quartz, and some specimens show little individualized orthoclase. Quartz only exceptionally forms grains 1 millimeter in diameter, and these ordinarily make up less than 10 percent of the rock; many specimens have the quartz confined to the micrographic groundmass. Augite is present in about half the specimens examined; in others it has been pseudomorphosed by hornblende. The hornblende is pleochroic in brownish green and yellow green and has an extinction angle of 17–18° C. Part of the hornblende has been altered to brown biotite, and other euhedral biotite crystals occur in most specimens. Most of the mafic minerals occur in clots, along with magnetite, sphene, and apatite. The groundmass of most specimens is a micrographic intergrowth of quartz and orthoclase, but other specimens have a monzonitic texture in which the orthoclase holds all the other minerals poikilitically, and a few specimens are microcrystalline, with the groundmass a granular aggregate of quartz, plagioclase, and orthoclase.

Many of the specimens examined have undergone mild hydrothermal alterations, with the development of epidote and chlorite after the mafic minerals and of sericite and a little albite after the plagioclase.

The rock ranges from porphyritic granodiorite to quartz monzonite, though most specimens should be classed as quartz-poor granodiorite.

CHEMICAL COMPOSITION

The following is a chemical analysis of the Schieffelin granodiorite from the roadside by Schieffelin's Monument, about 1½ miles northwest of Tombstone (Butler, Wilson, and Rasor, 1938, p. 25–26).

Schieffelin granodiorite

[R. C. Wells, analyst]

Bulk analysis		Normative minerals—Symbol I.4.4.3(4).	
SiO_2	62.33	Q	16.56
Al_2O_3	16.92	or	20.02
Fe_2O_3	3.95	ab	30.39
FeO	1.24	an	20.02
MgO	1.97	di { wo 0.70	1.30
CaO	4.48	di { en .60	
Na_2O	3.62	hy { en 4.30	4.30
K_2O	3.36	hy { fs	
H_2O-	.46	mt	2.32
H_2O+	.89	il	1.22
TiO_2	.63	hm	2.40
ZrO_2	.02	ap	.34
CO_2	.04		
P_2O_5	.17		
S	.03		
NiO	None		
MnO	.07		
BaO	.10		
SrO	.10		
Li_2O	Tr.		
Cu	Tr.		
Zn	None		
Total	100.38		

The chemical analysis is intermediate between the averages for quartz monzonite and granodiorite. The ratios of normative orthoclase to plagioclase for the average quartz monzonite and the average granodiorite of Daly are 0.48 and 0.32 respectively; in the Schieffelin rock this ratio is 0.40, almost exactly intermediate. The rock is here called a granodiorite in order to emphasize its difference from the several quartz monzonites of the area.

MAGMATIC RELATIONS

The other postorogenic intrusions of the region include the Stronghold granite and the Uncle Sam porphyry. Most of the Stronghold granite is much more siliceous than the Schieffelin and cannot be correlated with it on the basis of information at hand. The Uncle Sam porphyry occurs in close association with the Schieffelin but is older than the granodiorite. This makes a close magmatic relation between them much less probable than would a reverse age relation, for the Uncle Sam porphyry is more siliceous and contains plagioclase richer in albite than the Schieffelin. These characteristics are those normally found in more advanced stages of magmatic evolution and therefore make it improbable that the Uncle Sam and the Schieffelin were derived from the same local source, though of course it is possible that their ultimate magmatic reservoir was the same. If this is so the Uncle Sam porphyry must have differentiated farther in its transit to the levels now exposed for observation than did the Schieffelin, and have done this in considerably less time; for the andesite dike north of Bronco Hill apparently injected consolidated porphyry and was itself consolidated at the time of the injection of the Schieffelin. It is thus possible that the time that elapsed between the emplacement of these intrusions was so long that they should be referred to separate igneous cycles.

AGE

The age of the Schieffelin granodiorite is known only within rather wide limits. It is younger than the Uncle Sam porphyry, which is in turn younger than the Bronco volcanics. This formation is only indirectly dated but is not older than Late Cretaceous, and may be Tertiary. The upper Pliocene valley fill of the San Pedro trough rests unconformably on the Schieffelin granodiorite. The age is thus probably middle Tertiary, though it may be early Tertiary. This question is discussed more fully in connection with the structural evolution of the area.

DIKES RELATED TO SCHIEFFELIN GRANODIORITE

In the mining area at Tombstone a series of granodioritic to dioritic dikes cut the rocks of Mesozoic age along trends that do not deviate much from a N. 12° E. course and dip steeply to the west. These dikes have been described by Butler, Wilson, and Rasor (1938, p. 26–28), who point out probable relations to the Schieffelin granodiorite. These authors also show that the dikes are premineral and that the dikes have served to localize some of the ore deposits of the district. Their maps also show that many dikes have been faulted, both by normal faults of generally northerly trend and by eastward-trending faults such as the Prompter. These dikes were not examined during the present survey, so that nothing can be added to the discussion by Butler and Wilson.

North of Comstock Hill, just west of Tombstone, a few dikes of badly altered hornblende andesite porphyry cut the Schieffelin granodiorite. The original character of these rocks has been so obscured as to prevent satisfactory comparison with other andesitic porphyry suites, and these rocks may be only fortuitously associated with the Schieffelin granodiorite. However, they clearly represent a later cycle of igneous activity than the Bronco volcanics.

Near Brookline several narrow dikes and two or three pipelike masses of andesite porphyry (feldspar-rich vitrophyre) cut the Bronco volcanics. The freshness of these rocks suggest that they are younger than the main orogenic movements; they may be related to the Schieffelin granodiorite, though they are more likely still younger than that intrusion.

INTRUSIVE RHYOLITE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

Small bodies of rhyolitic intrusive rock are numerous in the area between Tombstone and the northwestern foothills of the Mule Mountains at the south edge of the map area. All the masses together probably cover nearly a square mile. For the most part, the rocks composing these bodies resist erosion somewhat more than the surrounding rocks and tend to stand out topographically though not very prominently.

GEOLOGIC RELATIONS

Several of these bodies in the Tombstone Hills form sills—the largest extends for about 1½ miles east from the 5,230-foot hill in sec. 25, T. 20 S., R. 22 E., and is about 500 feet thick at its western end. Other sills, on the northern hills southeast of Tombstone, are thinner, probably less than 100 feet on the average. For the most part, these sills are, as the name implies, closely concordant with the bedding of the enclosing rocks, but the largest one mentioned cuts sharply across the bedding locally for a few scores of feet. Some exposures of rhyolite in the pediment 2 miles southeast of Tombstone are overlain peripherally by an alluvial veneer, so that their wall-rock relations are concealed. Their petrographic resemblance to the definitely intrusive rocks is so close, however, that they may confidently be classed as the same formation. Many dikes in the Tombstone district are also composed of rhyolite porphyry, probably comagmatic with the rocks of the sills.

South of Tombstone Canyon, in the Mule Mountains near the south border of the map area, a body of rhyolite about 2,000 by 1,000 feet in cross section forms a plug cutting the limestone of the Naco group. This plug, which shows strong flow structures near its borders and cuts sharply through the surrounding limestone, is doubtless the remnant of a volcanic neck.

PETROGRAPHY

In the mass these bodies of rhyolite are pale pink and weather deep red brown. Many bodies, however, have apparently undergone hydrothermal alteration and are almost white. Both the fresh and altered rhyolite masses contrast boldly with the adjoining limestone.

In hand specimens the rocks all show crystals of quartz 1 to 2 millimeters across, untwinned feldspar of about the same size, and either well-formed minute books of biotite or irregular green blotches of chlorite, all in an aphanitic groundmass. Rocks from the plug south of Tombstone Canyon have a marked fluidal structure with strong vertical lineation parallel to the walls of the conduit, but the other masses of rhyolite appear nearly massive.

In many of the rocks the microscope adds but little to the megascopically determinable mineralogy. The quartz forms corroded and embayed crystals; the feldspar is in some specimens identifiable as orthoclase; in others the smaller optic angle suggests an approach to sanidine. A little oligoclase is present but is notably subordinate to the potash feldspar. In some specimens the oligoclase is albitized and sericitized. Biotite in some specimens is fresh; in others it is chloritized or even altered to muscovite. Minute accessory magnetite, zircon, and sphene are identifiable. The groundmass is microcrystalline in the sill rocks; in the plug rock it is microspherulitic.

It seems probable that these rocks are closely related to the rhyolite (aporhyolite) plugs described by Ransome from localities respectively 1 and 2½ miles northeast of Naco Junction (Ransome, 1904, p. 81–83). The partial chemical analysis of one of the rocks from near Naco further suggests their similarity to the ones here described, for they are notably poor in soda and lime, as the rocks of this area must also be.

AGE

From definite crosscutting relations, all that can be said of these rhyolite bodies is that they are post-Horquilla limestone. Their relation to the Comanche rocks, or even to the supposedly Tertiary rocks, is not directly to be inferred. However, some of the dikes in Tombstone Canyon, at the northwest end of the Mule Mountains, cut across faults that were presumably formed prior to the post-Paleozoic–pre-Comanche unconformity, so that there is little doubt that the rhyolites are at least as young as the Juniper Flat granite. Ransome apparently regarded all the intrusive rocks in the Bisbee area as belonging to the same magmatic cycle. However, in this more northerly area there is unequivocal evidence of at least three post-Paleozoic periods of large scale intrusion, and the question may well be raised as to the proper assignment of these rocks.

In this connection, no direct evidence in the area of this report relates the rhyolite bodies to the Comanche rocks, as in the case of the clearly pre-Comanche Juniper Flat granite. The rhyolites may be post-Comanche, even Tertiary. Tenney (1935, p. 225) has argued that the Sacramento Hill mass of porphyry at Bisbee is post-Cretaceous. While the evidence appears somewhat equivocal to one who has not studied the question on the ground, the presence of comparable siliceous intrusions of post-Comanche age (even though not definitely rhyolitic) here immediately to the north of Bisbee opens a question as to Ransome's assignment of these rhyolites to the epoch of the Juniper Flat granite. In particular, the microspherulitic textures of the rhyolite in the plug southwest of Tombstone

Canyon strongly suggests emplacement at shallow depths in the earth's crust. It is questionable whether such textures are compatible with an age as great as that of the Juniper Flat granite, some typical masses of which occur within a few hundred feet, in the same structural block as the rhyolite plug. Furthermore, the marked similarity of the rhyolites in the whole district from Naco to the Tombstone Hills, a distance of over 20 miles, and their occurrence in rocks of widely different stratigraphic levels and structural relations suggest a relation between texture and the present topography not to be expected of a pre-Cretaceous intrusive series in this region of marked Tertiary deformation. Accordingly, although no definite dikes of this rhyolite have yet been found in the Comanche rocks of the region, it seems best to assign them questionably to the Tertiary(?).

STRONGHOLD GRANITE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The domes and spires that rise above the narrow canyons of Cochise Stronghold are carved from a mass of intrusive rock which is here called the Stronghold granite. This mass is the major element in the geology of the Dragoon Mountains between Middle Pass and Mount Glen, where it is exposed over an area of about 24 square miles. Doubtless it extends considerable distances beneath the alluvium to the east and west of the range. Smaller bodies of rocks that are similar petrographically and in geologic relations, and are referred to the same formation, occur along the lower western slopes of the Dragoon Mountains between Fourr Canyon and Jordan Canyon.

No doubt the Indians chose their stronghold because permanent springs are found there and the towering crags offered shelter for the defenders, so that a few men could hold the country against a considerable detachment of troops. Although the canyons that penetrate this part of the range have gentle gradients, they are narrow; and some of the side canyons have walls that literally overhang, so that the higher slopes are nearly inaccessible. A better natural fortress would be difficult to find. The whole area of this formation is a land of steep cliffs, where walls abound that can hardly, if at all, be scaled. Although many of the highest peaks of the range are capped by hornfels bordering this intrusion, rather than by the intrusion itself, there can be little doubt that it is one of the formations of the area most resistant to erosion.

GEOLOGICAL RELATIONS

The Stronghold granite is the youngest major intrusion of the region. It cuts the Dragoon thrust sheets in many places and at one place or another is found in intrusive contact with representatives of all the rocks from Pinal schist to the Bisbee formation.

Most exposed contacts of the Stronghold granite are clean cut and distinct, and the country rocks are sharply transected without any noticeable distortion that could be attributed to intrusive pressure. This is particularly clear along the northern contact, south of Mount Glen and along the north slopes of Stronghold Canyon (Benson quadrangle). Some overturned folds as well as warped thrust sheets here dip into the intrusion at gentle angles; and although they can be seen in several canyons to be underlain by part of the granite, their structure at the contact is in undeviating continuation of that farther to the north. Much of the southern contact shows the same indifference to the structure of the wall rocks, though the long strike projection of the thrust sheets northwest of China Peak shows that, in part, this border of the intrusion was outlined by preexisting surfaces of weakness. The conclusion that the dominant process of emplacement of the mass was permissive rather than forceful injection seems inescapable, even though, as shown on structure sections, there has been some doming of the thrust surfaces as a whole. That is, the intrusion is roughly central to a culmination of the thrust sheets. This doming does not appear to be more emphasized near the granite mass than some other axial culminations not obviously associated with intrusive rock.

The Stronghold granite is conspicuous among the intrusive rocks of the region in the pronounced contact-metamorphic effects that it has exerted on all the other rocks. From Middle Pass northward, most of the rocks of the range are hornfels. The thermal metamorphism due to this intrusion is superposed on the thrust breccias and transgresses major fault surfaces at so many places that there can be no doubt that the granite was emplaced after the major thrust faulting of the range. If the dikes in the Bisbee formation between Courtland and Middle Pass are correctly referred to this intrusion, they furnish further evidence in this direction, as they are undeformed and cut the overturned beds of the Bisbee. However, in the small outlying masses referred to this granite between Fourr Ranch and the mouth of Jordan Canyon, protoclastic textures and other features suggest that not all of the orogenic stresses had been relieved at the time of intrusion. Such stresses were, however, not sufficient to produce any apparent mineral parallelism in the rock.

PETROGRAPHY

Three major variants of the Stronghold granite have been recognized: the main facies, the porphyritic border facies, and the aplitic facies. These three facies differ appreciably only in grain size and the proportions of the minerals present, not in the composition of their minerals. All are poor in dark minerals, so that the name alaskite would be perhaps appropriate for any of them.

The main facies of the granite ranges from light gray to light pink and weathers buff. It is rather coarse grained, with microcline crystals ranging from 1 to 20 millimeters across and averaging perhaps 6 millimeters. The quartz crystals attain 10 millimeters but average about 4 millimeters in diameter, and the plagioclase crystals are perhaps somewhat smaller. Plagioclase is definitely subordinate to microcline in nearly all specimens examined. Biotite forms dark-brown splendant flakes that only locally constitute as much as 5 percent of the rock. They average 1 or 2 millimeters in diameter, though sporadic flakes are as much as 1 centimeter across. Small quantities of muscovite are found everywhere; and in local areas, notably near Fourr Canyon, it is the more abundant mica. Thin sections show that the plagioclase is a slightly zoned sodic oligoclase, ranging to albite, An_{15}–An_8. Locally some sericite has been developed in the more calcic cores of the crystals, but most of the plagioclase is water clear. Quartz and microcline-microperthite are about equally abundant. Biotite, which is strongly pleochroic in yellow brown and deep greenish brown, is generally accompanied by a trifling amount of muscovite, but in some specimens muscovite has replaced nearly all of it. In the slightly sericitic specimens the biotite is partly chloritized also, but this is not common. Magnetite is the most abundant accessory mineral; notably large zircon crystals and much less abundant rutile, sphene, fluorite, tourmaline, and apatite also occur.

In some specimens, representing minor variants both of the main body and some of the small masses between Fourr and Jordan Canyons, muscovite forms wormlike intergrowths with microcline. These rocks also have conspicuous amounts of myrmekite, and muscovite has replaced most of the biotite, though not completely. The quartz appears to have corroded most of the other minerals, and there is more than the usual amount of protoclastic texture. It is inferred that deformation of the partly consolidated intrusion was more severe in these areas than elsewhere; for although minor traces that might be called protoclastic can be found in nearly any specimen of the rock, it is mostly a normal granitic (hypidiomorphic granular) texture. The plagioclase microcline ratio ranges from 2:3 to 1:4, and as the plagioclase is highly sodic, the rock is appropriately called a biotite granite.

The rock of the border facies is porphyritic, though not conspicuously, at least in hand specimens. Sporadic crystals of microcline that range from 1 to 4 millimeters in diameter and quartz crystals of about the same size are found in a groundmass of ½ to 1 millimeter grain. Biotite is the only dark mineral recognizable with a hand lens, and as in the normal facies, into which the border facies grades imperceptibly, muscovite is recognizable in places and exceptionally is the dominant mica.

The microscope shows that the composition of this rock is essentially the same as that of the main facies. Sodic oligoclase (An_{15} to An_{10}), microcline-microperthite, quartz, and biotite are the principal minerals. In some specimens, quartz and microcline form phenocrysts distinguished sharply in size from the groundmass components, but in most the porphyritic texture is seriate; and in these, considerable plagioclase is also present among the phenocrysts, though everywhere subordinate to the other light minerals. Muscovite is associated with the biotite in some specimens; in others it is found as a wormlike intergrowth with the microcline. There is little sericite in these rocks, though locally a little chlorite has developed at the expense of the biotite. The same accessory minerals are present as in the main facies. As in that, the groundmass textures are chiefly normal granitic; but in places there are traces of protoclastic texture, and in others the texture approaches panallotriomorphic. No consistent difference exists in the proportions of the minerals present in the two facies, and the rock, like the main mass of the intrusion, is also considered an alaskitic biotite granite. No attempt was made to distinguish the two facies in mapping, but the impression was gained that the volume of the porphyritic facies is trivial in comparison with that of the main mass.

The aplitic facies differs very slightly from the border facies, though it seems to contain even less biotite. It forms nearly white outcrops that weather light buff gray. It was not distinguished in mapping, but appears to be unusually abundant just northwest of Cochise Stronghold and also southeast of Slavin Gulch near the striking group of cliffs to which the fanciful name Sheepshead has been locally given. Although some of its contacts with the main facies are abrupt, others are apparently gradational, and the rock is regarded as too closely related to the main mass to warrant the expenditure of the time necessary for its discrimination in mapping.

Although most of this facies is truly aplitic, with fine grain and panallotriomorphic texture, there are some granophyric varieties and some porphyritic rocks that are either gradational to the aplites or at least megascopically resemble them so closely that the cursory attention given them in the field did not suffice to distinguish them from the aplites. These rocks differ from the two varieties just described only in their textures and in their extreme poverty in biotite, which appears to make up less than 3 percent of the rock.

CHEMICAL COMPOSITION

Two specimens of the Stronghold granite have been analyzed; one of the normal facies, the other of the aplitic variety. The analyses show that the Stronghold granite is notably richer in alkalies and poorer in calcium than any of the other plutonic rocks of the area that have been analyzed. It seems to represent, as its structural relations suggest, a plutonic cycle independent of all the others.

Analyses of Stronghold granite

[Lee C. Peck, analyst]

Bulk analysis			Normative minerals—C. I. P. W. symbols: Normal facies, I. 4. 2. ″4; aplitic facies, I. 3(4). 1(2). 3″.		
	Normal facies	Aplitic facies		Normal facies	Aplitic facies
SiO_2	67.78	76.71			
Al_2O_3	17.30	13.02	Q	18.84	36.42
Fe_2O_3	.73	.73	or	22.80	25.58
FeO	.91	.29	ab	42.44	31.44
MgO	.45	.11	an	9.17	3.06
CaO	2.22	.61	C	1.53	1.02
Na_2O	5.05	3.73	il	.46	.15
K_2O	3.88	4.28	mt	.93	.70
H_2O+	.45	.25	hm	------	.16
H_2O-	.20	.06	hy {fs .92; en 1.10}	2.02	{--- ; .30} .30
TiO_2	.21	.12			
P_2O_5	.12	.02	ap	.34	------
MnO	.07	.03	fl	.10	------
BaO	.13	n. d.			
F	.14	n. d.			
CO_2	.10	n. d.			
	99.74	99.96			
Less O for F.	.06	-------			
Total	99.68	99.96			

SILICEOUS DIKES RELATED TO STRONGHOLD GRANITE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

Dikes of granite porphyry, quartz porphyry, and rhyolite porphyry are abundant in the eastern foothills of the Dragoon Mountains between North Courtland and the mouth of Middle Pass, where they form a swarm trending northwest about parallel to the strike of the Bisbee formation. A few similar dikes are found on the west side and top of the range, to the south of Middle Pass, where they cut the intricately faulted Paleozoic rocks without offset on any of the faults. In the foothills country the principal ridges are formed by these dikes, which are obviously more resistant to erosion than the Bisbee formation; but on the main ridge the dikes are not conspicuously expressed in the topography as the Paleozoic limestones are also relatively resistant rocks.

GEOLOGICAL RELATIONS

As just noted, the dikes are not offset on any of the many faults they cross in the main range. In the area to the east they invade the Bisbee formation, where it lies in overturned position, and shows no faults or other signs of having been deformed after emplacement. Although the trend of the dikes in this area is about parallel to the strike of the Bisbee formation, the dikes dip generally more steeply than the beds, so that they are only locally sill-like.

None of the dikes just mentioned can be traced into the main mass of the Stronghold granite; in fact, they are most abundant and thickest well to the south of the main mass. There is, however, considerable evidence that the roof of the main intrusion dips rather gently to the south along the west border of the range, and it is entirely possible that another cupola may underlie the region of most abundant dikes, though it does not crop out. The structural relations of the dikes point to a postthrust age, as do those of the Stronghold granite mass; and the petrographic characters of the dike rocks are such as to suggest rather strongly a consanguinity between them and the Stronghold granite.

PETROGRAPHY

The rocks composing these dikes range from very fine-grained felsites to granite porphyry, though it seems that these variations are due more to local conditions of chilling than to primary magmatic characters. All the dike rocks are light pinkish gray to yellowish gray and weather to light tan or light brown. Some specimens contain abundant phenocrysts of quartz and pink feldspar as much as 5 millimeters across, others contain only smaller quartz phenocrysts, and still others are practically aphanitic, though showing sparse crystals of quartz. In the specimens with the larger phenocrysts, the groundmass is wholly crystalline; and quartz, two varieties of feldspar, and a little biotite are recognizable with the hand lens; in the specimens with smaller phenocrysts, the groundmass is dense and aphanitic.

Under the microscope some of the rocks are seen to have undergone hydrothermal alteration, though many are almost unaltered. The minerals identified include quartz, commonly somewhat resorbed rhombic crystals; orthoclase, in some specimens perthitic; oligoclase-albite, which has altered to slightly sericitic albite in some specimens; biotite, very subordinate; a little muscovite; and, in one specimen, a few small crystals of green hornblende. The textures range from microgranitic porphyritic through granophyric to porphyritic with a spherulitic groundmass. It is probable that this range in textures correlates with the width of the dikes, and hence with the rate of cooling, as the thicker ones are more coarsely crystalline than the thinner ones. None of the dike rocks shows more than trivial signs of mechanical deformation. The composition of the dike rocks is not closely similar to that of any of the younger siliceous volcanic rocks but is closely comparable with that of the Stronghold granite. These features are such as would be expected if the magma of the Stronghold granite were injected under conditions of quick chilling, and the dikes are therefore regarded as probably comagmatic with that mass.

LAMPROPHYRE (SPESSARTITE) DIKES

DISTRIBUTION

A few narrow lamprophyric dikes cut the Stronghold granite and the bordering Paleozoic rocks to the north in the region between the Fourr Ranch and the east side of Mount Glen. They were also noted farther south, near Cochise Peak and Middle Pass. Far to the southeast similar dikes are found in the Gleeson quartz monzonite, widely distributed from Gleeson toward Hay Mountain, and northwestward toward South Pass. Despite the considerable distance—10 to 18 miles—from these localities to the nearest exposures of the Stronghold granite, this southern group of dikes closely resembles the northern both petrographically and structurally and is here included with that group.

PETROGRAPHY

The rocks of this suite are all dark greenish gray, weathering to somewhat lighter gray hues. They contain phenocrysts of hornblende in a groundmass of hornblende and feldspar, as is determinable with the hand lens. All are considerably altered, and chlorite and epidote can commonly be identified. The microscope shows the rocks to be true lamprophyres, with panidiomorphic textures. The phenocrysts are now chiefly hornblende, though some grains show cores of augite, and most show considerable alteration to epidote, chlorite, sericite, and calcite. The groundmass contains much hornblende and plagioclase, both somewhat altered. The least altered plagioclase is identifiable as sodic andesine, but most of it is so crowded with alteration products, such as calcite and sericite, as to be unidentifiable. A few specimens contain a little orthoclase. Magnetite and apatite are relatively abundant accessories. Some contain ocelli of quartz, rimmed by the usual reaction minerals. The rocks are all lamprophyres and are best classed as spessartite.

AGE AND RELATIONSHIPS

Such mafic rocks with large proportions of chlorite, calcite, sericite, and epidote should be extremely sensitive to mechanical deformation. None of the specimens examined show even the slightest traces of mechanical disturbance. Accordingly, it seems clear that the rocks were injected after the major deformation of the region. Indeed, this is particularly obvious with the northern dikes, for many of them cut faults and the contact of the posttectonic Stronghold granite without offset. The rocks of the southern group cut the highly deformed Gleeson quartz monzonite, yet show by their textures that they could not have undergone any deformation comparable to that of their wall rocks. They are petrographically so similar to the dikes of the northern group that they are probably derived from the same source and are here correlated with them. No postorogenic plutonic mass other than the Stronghold granite is known in the area, and the inference is accordinlgy drawn that these dikes are probably related genetically to that intrusion. The occurrence of these dikes far to the southeast of the surface exposures of the Stronghold granite may perhaps be regarded as a further suggestion of persistence of the Stronghold mass in this direction at depth. This supplements the inference based upon the southerly occurrences of dikes of granite porphyry and related rocks that also show affinity to the Stronghold granite.

VOLCANIC AND SEDIMENTARY ROCKS YOUNGER THAN LOCAL THRUST FAULTS

SEDIMENTARY ROCKS OLDER THAN S O VOLCANICS

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

Outcrops of sedimentary rocks younger than the Bisbee formation and older than the S O volcanics are found in the neighborhood of Outlaw Mountain and farther west, in the area between the Tombstone Hills and the S O Ranch. Exposures in the easterly localities are confined to stripped parts of the pediment there developed; in the westerly localities they are limited to the bottoms and sides of stream valleys incised in the valley fill. Their wide distribution would hardly be suspected in a cursory examination of the country.

STRATIGRAPHY

These rocks crop out in small and scattered areas and are found in depositional contact with older rocks only in the locality about a mile south of Outlaw Mountain. Here the sedimentary rocks rest on a rather smooth erosion surface carved on the Gleeson quartz monzonite. They consist of conglomerate, interbedded with maroon sandstone, mudstone, and pink clays. The conglomerates contain cobbles up to 5 inches in diameter of quartz monzonite, rhyolite, andesite, and limestone. Several hundred feet of such strata are exposed here. They dip eastward at angles between

10° and 30° and are unconformably overlain by quartz latite which is here correlated with the lower member of the S O volcanics.

In the valley south and southeast of Stockton Hill, there are poorly exposed white, sugary sandstones interbedded with conglomerates containing cobbles of maroon mudstone that seem to be derived from the Bisbee formation. These rocks are standing at high angles and are intimately mixed, in what must be a closely faulted complex, with fossiliferous limestones of the Bisbee formation. The exposures are too poor to determine anything of the stratigraphic succession, but the beds are clearly older than the S O volcanics and also had undergone complex faulting before that formation was deposited.

The sporadic exposures in the valley of Walnut Creek and its tributaries east of Tombstone, where the Recent drainage has carved through the Quaternary gravels and underlying conglomerate referred to the Gila conglomerate, are of conglomerate, sandstone, mudstone, and thin purple limestone. In some of these outcrops, fully 80 feet of beds are exposed, and their attitudes range from nearly flat-lying to dips of 25°. The sandstone and mudstone beds are much like those of the Bisbee formation, but purple limestones such as occur here are not known elsewhere in the Bisbee formation of the area, and the conglomerate beds contain well-rounded cobbles of quartzite and of maroon mudstone like that in the Bisbee formation. It seems certain that no locally known rocks older than the Bisbee could have furnished these pebbles of mudstone, and the series containing them is therefore regarded as younger than that formation. These conglomerates also contain pebbles of andesite and felsite. Although these could have been derived from the pre-Bisbee volcanic rocks known in the Dragoon quadrangle to the north, there is no local evidence of intra-Bisbee disturbance, so that the maroon mudstone cobbles are not readily explained by intraformational erosion. In most of these localities the rocks in question are unconformably overlain by conglomerates referred to the Gila, or by Quaternary terrace gravels. However, in secs. 15, 21, and 22, T. 20 S., R. 23 E., these rocks are overlain, with angular unconformity, by the S O volcanics.

AGE AND CORRELATION

No fossils have been found in any of these small exposures, so that no definite age assignment can be made. That the rocks are older than the S O volcanics, and hence almost surely pre-Pliocene, seems clear. They are believed to be almost as certainly younger than the Bisbee formation, though this may be less certain in view of the many lithologic similarities between the two series. The definite Bisbee formation of the Tombstone Hills contains no recognizable volcanic rocks, whereas this series contains abundant pebbles of andesite and felsite. Though rocks which seem not to be separable from the Bisbee formation in the area between the northern Courtland Hills and South Pass also contain volcanic rocks of similar composition, no pebbles of consolidated maroon mudstone were found in the eastern locality, whereas they are abundant in the series exposed in the gulches tributary to Walnut Creek. The beds exposed south of Outlaw Mountain, though tilted, have not undergone any strong deformation such as would seem to be implied if they had been in their present positions during the intense brecciation of the Gleeson quartz monzonite, upon which they rest. It seems safe to assign this series to a time later than this strong deformation, and thus a Tertiary age seems reasonable.

S O VOLCANICS

NAME

A thick series of interbedded quartz latite tuffs and hornblende andesite flows is exposed near the S O Ranch and is here named from that locality, in sec. 20, T. 20 S., R. 24 E. The difficulties of correlating rocks of local source over wide intervals and the discontinuities in exposures that prevent tracing from one locality to another seem to render it desirable to distinguish these rocks from the Pearce volcanics and the several volcanic series in the San Pedro Valley to the west, despite the fact that there are many similarities between them. This distinction is especially desirable in view of the differing structural relationships of these several volcanic successions.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The S O volcanics are well exposed between the south end of Hay Mountain and the hills southwest of Reeves Ranch, about 8 miles to the northwest. Outlying bodies, referred to this formation on grounds of greater or less certainty, occur south of Cowan Ranch, near Outlaw Mountain, and as sporadic masses exposed on the pediment that extends northwest of Outlaw Mountain to the Gleeson–Tombstone road. A few small outcrops are found still farther north, on the west side of the Dragoon Mountains near the Bar O Ranch, in secs. 27, 28, 33, and 34, T. 19 S., R. 24 E.

The lower members of the S O volcanics are weakly consolidated tuffs with little resistance to erosion; they are in general poorly exposed except where some of the more resistant overlying members are preserved and rise in cuestas above them. The hornblende andesites of the formation are flows and form prominent hills and mesas, and the quartz latite tuffs of the upper part of the formation are also relatively resistant and form the hogback of Hay Mountain—a landmark so prominent that it has been utilized as the site of an airplane beacon visible for many miles to the east, southeast, and west. Thus, in general the upper parts of the formation are topographically conspicuous and are well exposed; but the lower parts form areas of low relief, and their relations are less clear.

GEOLOGICAL RELATIONS

Most of the contacts of the S O volcanics with older rocks are faults, and their original relations can be determined in but few places. The volcanic rocks clearly accumulated upon an older erosion surface of considerable relief, so that in various localities different members lie at the stratigraphic base of the formation. Thus, just south of the Gleeson–Tombstone road in sec. 33, T. 19 S., R. 24 E., quartz latite tuffs rest upon the Gleeson quartz monzonite, with an irregular erosion surface separating the two. On the other hand, in several exposures on the north slope of the hill in sec. 18, T. 20 S., R. 24 E., hornblende andesite flows of the S O volcanics rest directly on the Bisbee formation, although at some localities thicknesses of 10 feet of quartz latite tuff intervene. Southeast of Outlaw Mountain the quartz latite tuff rests in apparent conformity upon red-brown sandstones and mudstones that overlap the Gleeson quartz monzonite on an irregular surface; probably these underlying sediments, described in the preceding section, are of post-Comanche age, but it is possible that they are a local aberrant facies of the Bisbee formation.

The S O volcanics are overlain in most localities by the undeformed late Quaternary alluvium. However, near the Reeves Ranch the volcanic rocks are unconformably beneath tilted volcanic gravels that must be either of early Pleistocene or, more probably, of greater age. (See p. 119.) Although the S O volcanics have been themselves notably tilted and faulted, there is nothing to suggest that they were involved in the thrust faulting that has affected the region and some evidence that they were not.

STRATIGRAPHY

GENERAL FEATURES

The S O volcanics are highly variable both laterally and vertically. This variability is doubtless due in large part to the local sources of the material contributed to the formation, in part to the considerable relief of the prevolcanic surface, and probably in part to intervolcanic deformation.

The formation is broadly divisible into three members: a basal series of quartz latite tuffs, breccias, and minor obsidian flows, with interbedded conglomerates, sandstones, and mudstones that are also largely of pyroclastic origin; an intermediate member of hornblende andesite flows; and an upper member of quartz latite tuff, with a few local intercalations of true rhyolite and hornblende andesite. The hornblende andesite flow member is apparently the most uniform and continuous part of the formation; but owing to faults and the presence of thinner local flows of apparently identical lithology within the overlying tuff, the prominent flows are possibly not all at the same stratigraphic level. The following discussion of the formation is, however, based on the probability that the thicker hornblende andesite parts are essentially contemporaneous.

LOWER MEMBER

The basal unit of quartz latite tuffs and water-laid sandstones ranges in thickness from about 1,600 feet on the southeast face of Stockton Hill to a knife edge just across the valley to the south—and is missing within about a mile in that direction. The Stockton Hill section is apparently the thickest exposed in the area and is incomplete as it is cut off by one of the faults of the horst system in that region.

The lower part of the S O volcanics exposed on the southeast side of Stockton Hill consists dominantly of fine- to medium-grained tuffs, chiefly light gray to pink and white and in beds that range up to 20 feet in thickness. A prominent ledge, about 500 feet above the lowest exposed bed of this section, is formed by a dark flow-banded obsidian flow about 20 to 40 feet thick. This obsidian contains abundant inclusions of a wide variety of rock types—quartzite, limestone, sandstone, and granitoid varieties—with streaks of black glass in a devitrified groundmass. (See pl. 4*A*.) It may be transitional between a true lava and a welded tuff. Some thin sandstones and grit beds are present both below and above this conspicuous layer, and a little higher there is a coarse gritty sandstone, strongly crossbedded and conglomeratic at the base. Above this is an unbedded explosive tuff breccia, with fragments of obsidian and hornblende andesite up to an inch or so in diameter in a fine matrix—probably a product of peléan, or "glowing cloud" eruption. It is from 60 to 100 feet thick and locally forms the top of the lower member of the formation as it is directly overlain by the hornblende andesite flows that cap Stockton Hill. The whole member beneath the andesite is so variable that no detailed measurements were made of it; however, the bulk thickness on the south side of Stockton Hill is about 1,600 feet.

All the rocks of this member are dominantly pyroclastic, and even the water-laid beds consist mostly of reworked volcanic debris. Much of the material is vitric, but phenocrysts of quartz, sanidine, plagioclase, and biotite are sporadic in the coarser fragments and are seen, under the microscope, to make up most of the mineral grains present. The bulk of the member is composed of vitric fragments.

Across the valley to the south beneath the hornblende andesite flows that cap the hill in the N½ sec. 18, T. 20 S., R. 24 E., the quartz latite tuff is present only in small lenses that nowhere exceed 10 feet in thickness and a few scores of feet in length. Elsewhere on this hill and notably all along the west side, the hornblende andesite rests directly on the Bisbee formation.

Three small hills underlain by the Bisbee formation in the SW¼ sec. 7, T. 20 S., R. 24 E., and the SE¼ sec. 12, T. 20 S., R. 23 E., southwest of Stockton Hill, are capped by thin plates of porphyritic andesite. This andesite may be the basal unit of the lower member of the S O volcanics, as its structural position suggests, but no similar rocks were elsewhere found in the formation. Inasmuch as the base of the volcanic rocks in the fault block that includes Stockton Hill is concealed by faulting, the stratigraphic position of these andesite remnants is not certain.

Petrographically, the andesite of these small outliers differs notably from the hornblende andesite of the middle member of the volcanic rocks. On fresh fracture, the rock is pink, with glistening phenocrysts of plagioclase abundantly distributed through it, along with small mafic clots and small amounts of pyroxene. It weathers to a light tan. Under the microscope the andesite can be seen to be composed of plagioclase, in phenocrysts as much as 1.5 millimeters long, zoned from An_{70} to An_{50}; hypersthene, in much smaller phenocrysts; and considerable opaque material that is probably hematite, pseudomorphous after hornblende. The texture is pilotaxitic. The rock resembles some of the Pearce volcanics or the andesitic rocks east of South Pass much more than the nearby hornblende andesite of the middle member of the S O volcanics.

Farther west, in the E½ sec. 11 and W½ sec. 12, T. 20 S., R. 23 E., this member has a series about 400 feet thick of greenish-brown fine-grained arkosic sandstones and mudstones in its lowest exposed part; the basement upon which it rests is not visible. These rocks are folded into an open, northwestward-pitching anticline and are exposed over an area of about 400 acres. The beds range from 6 inches to a few feet thick and consist chiefly of volcanic material, except that some of the sandstones contain some pebbles of nonvolcanic origin. There are also a few beds of arkose that consist largely of debris probably derived from the Gleeson quartz monzonite. A few thin beds of light-yellow-gray tuff are present, and these increase in number and thickness upward.

In hand specimens, these water-laid sandstones appear to be simply arkose, consisting of subordinate quartz, altered biotite, and some feldspar associated with much chalky-appearing material of about the same grain size, which was mistaken in the field for decomposed feldspar. In thin sections, however, it can be seen that nearly all this dull-weathering material consists of fragments of volcanic glass, most of which are devitrified; and the mineral grains are present in only about the same proportions as they are in many of the interbedded recognizable tuffs. Although thin sections of the interbedded siltstones and mudstones were not studied, it seems probable that these, too, are merely water-laid volcanic ash and the entire member is thus mainly a quartz latite pyroclastic deposit.

Toward the west and northwest these rocks appear to grade upward into tuffs with less and less water-laid material and are overlain by about 100 feet of massive light-gray tuff-breccia that is essentially identical with that immediately beneath the hornblende andesite on Stockton Hill. This tuff-breccia contains fragments of hornblende andesite, obsidian, and pumice lapilli. Practically no sorting or bedding is discernible, and the rock appears to be the product of feeble peléan eruptions. As at Stockton Hill, this tuff-breccia is immediately overlain by hornblende andesite lavas; here, however, the two formations are clearly unconformable, as the lavas do not show the anticlinal fold of the lower beds. It seems probable, though exposures are not sufficiently complete to prove it, that there was a period of deformation between the deposition of the pyroclastic rocks and that of the overlying lavas. That such a period was geologically brief seems probable from the presence within the pyroclastic rocks of andesitic fragments that are very similar to, if not identical with, the material of the overlying flows.

As at Stockton Hill, the lower member of the S O volcanics in this western locality also thins markedly to the south. About a mile east of the Reeves Ranch there is about 600 feet of this member exposed; 2 miles to the south there is less than 100 feet.

MIDDLE MEMBER (HORNBLENDE ANDESITE)

The middle member of the S O volcanics is composed of a series of hornblende andesite lavas. Although there are a few thin flows higher in the section, in the midst of the upper member of the volcanic rocks, it seems likely that the bulk of the andesite flows belong to about the same period of eruption; and in the interpretation of the structure and history of the area this assumption has been made. Thus, the hornblende andesite body that extends for about 2½ miles northwestward from the north end of Hay Mountain is regarded as the same as that capping both Stockton Hill and the hills to the south and west of Stockton

Hill as far as the center of T. 20 S., R. 23 E. Small outliers that occur north of the Gleeson–Tombstone road, near the Bar O Ranch, near the common corner of secs. 28 and 34, T. 19 S., R. 24 E., belong to the same member or represent some of the higher flows.

The hornblende andesite, a relatively resistant rock, forms the cap rock of several prominent mesas and cuestas; but the most easterly of its main bodies, that north of Hay Mountain, forms a lowland beneath the tuffs of the upper member of the formation. Here the andesite is poorly exposed; and inasmuch as it is so wide in outcrop and apparently dips rather steeply westward and hence represents a considerable thickness of lava, its subdued topographic expression led to the suspicion that it might not be the same as the prominent cliff-forming member on Stockton Hill and elsewhere toward the west. However, it is petrographically identical with rocks from these more westerly exposures and appears to be in the same relative stratigraphic position, so that its low relief must either be due to unseen structural features or, more probably, to the local physiography.

The hornblende andesite member is probably about 1,000 feet thick east of the S O Ranch, where its base is concealed by a fault; about 400 feet thick on Stockton Hill; and about 300 feet thick south of the Reeves Ranch. Although only components of its thickening can be determined and not the full amount or direction of it, the member thus appears to thicken to the east, rather than to the north as does the lower member.

For the most part, the hornblende andesite forms platy flows, with the general platy fracture about parallel to the flow boundaries, which are not conspicuous. Locally there is a little columnar jointing normal to the flow boundaries, especially in the lower flows on Stockton Hill.

Hand specimens range from light to purplish gray and from dense lithoidal rocks that contain practically no phenocrysts to notably porphyritic rocks that contain dark, oxidized hornblende—crystals as much as 3 centimeters long—or oxides that have the forms of hornblende crystals. Feldspar does not form phenocrysts in the member, though it can be recognized as a constituent mineral with the hand lens. The hornblende crystals have a marked parallel arrangement, generally trending northeast or east and possibly marking the direction from which the material flowed. The andesitic plug in the pediment northeast of Outlaw Mountain may represent one of the sources of these lavas. (See p. 115.)

Thin sections show the rocks to be more uniform than might be inferred from hand specimens. Generally hornblende is the only phenocryst, though one or two specimens show a little augite that has been largely replaced by hornblende. Most of the hornblende has been oxidized and now has the properties of basaltic hornblende, with a small extinction angle and pleochroism in brown, though some is normal green hornblende. In many specimens no amphibole is present, but dark oxides, probably magnetite and hematite, occupy areas that clearly were inherited from amphibole. The groundmass is typically andesitic (pilotaxitic) and contains minute grains of augite commonly, hypersthene less commonly, and the usual accessories, apatite and magnetite, together with the predominant plagioclase. Although the plagioclase is strongly zoned (An_{65}–An_{25}), most of it is sodic andesine, near An_{35}. Some specimens contain a little orthoclase and some, a little interstitial quartz; but these are trivial in amount. Biotite occurs in two of the many specimens examined but is also accessory. Some of the specimens are altered and contain epidote, chlorite, and a little sericite; but, on the whole, the rocks are fresh.

These andesites differ from those of the Pearce volcanics in the rarity of augite and plagioclase as phenocrysts, in the occurrence of hypersthene and augite exclusively in the groundmass, and in the generally more sodic composition of the plagioclase. They also contain a higher proportion of hornblende than the Pearce rocks, so that there appear to be sufficient differences between the two suites to warrant the separation here made. They also differ from the andesites east of South Pass in that they are practically without feldspar phenocrysts, which are so prominent in the rocks of the more northerly locality.

UPPER MEMBER

Overlying the hornblende andesite in the more easterly areas of the S O volcanics are the quartz latite tuffs of the upper member. These higher tuffs (above the andesite) are found from the hogback a mile south of Cowan Ranch, their most southerly exposure, northwestward to a point near the middle of sec. 18, T. 20 S., R. 23 E., and also in the SW¼ sec. 8, T. 20 S., R. 24 E. Presumably they extended farther westward at one time but have since been removed by erosion. The prominent hogback of Hay Mountain is made up of these tuffs, as are also a series of lower ridges and cuestas farther northwest. The thickness is about 1,100 feet on Hay Mountain; elsewhere it is much less.

The member is dominantly composed of quartz latite tuffs and subordinate flows with only a few beds of conglomeratic sandstone, and one or two thin flows of hornblende andesite. The base is ordinarily not well exposed, owing to talus cover; but where it can be seen, the tuffs seem to be conformable with the underlying andesite. Probably there was local erosion of the andesite, however; for in a conglomeratic sandstone exposed on the east face of Hay Mountain and in another on the hogback a mile south of Cowan Ranch, there are pebbles of hornblende andesite like that of the underlying flows. In addition to these pebbles of andesite, the conglomerates contain pebbles of granite resembling the Juniper Flat granite, chert, sandstone that resembles some of those of the Bisbee formation, limestone, and rhyolite or quartz latite. These conglomerate beds are locally as much as 100 feet thick, but they do not appear to be persistent, and all the water-laid material of the member probably does not constitute as much as 5 percent of it.

The tuffs and tuff-breccias are mostly in thick beds and are probably subaerial deposits as no internal stratification is visible. They are white, light gray to pinkish on fresh fractures, and weather to light brown. Commonly they are poorly sorted, with abundant lumps of pumice an inch or two across and a few that are a foot or even 2 feet in diameter, in a fine matrix.

In hand specimens, crystals, 1 to 3 millimeters in diameter, of quartz, plagioclase, opalescent sanidine, and biotite, can be identified in a vitric to aphanitic groundmass. In some places, notably in the low hills in the SE¼ sec. 18, T. 20 S., R. 23 E., the rocks, on fresh fractures, give uniform reflections over surfaces several centimeters across, determined by the cleavage planes of calcite; the tuff is cemented by "sand calcite," which encloses the other components poikilitically. The matrix is either dull gray or pink and largely glassy. The rocks are distinguished from the quartz latite tuffs of Sugarloaf Hill by the abundance of sanidine among the phenocrysts.

In thin sections, plagioclase is generally more abundant than the sanidine and has an average composition of andesine close to An_{35}. It is generally fresh and unaltered. The sanidine is essentially uniaxial in most specimens. The quartz is generally in somewhat resorbed crystals, but traces of an original bipyramidal form are present. The biotite is brown; many crystals are zoned, with a deeper brown border. Sporadic individual crystals of basaltic hornblende, augite, and labradorite occur in a few specimens; they are interpreted as xenocrysts. Many of the phenocrysts are broken, and the adjacent pieces are unrelated, so that viscous flow is not the probable cause of the fracturing. Most of the rocks show shard structures and collapsed vesicles; a few have spherulitic textures that are younger than the shards. These spherulites apparently formed at the same time as the shards were devitrified with the development of cryptocrystalline quartz and feldspar normal to the surfaces of the fragments. Many of the rocks are thus believed to show the characters of welded tuffs or ignimbrites. Others appear to be normal nonwelded tuffs. All have the mineral composition appropriate to quartz latite tuffs. Associated with these more abundant tuffs are a few definite flows of rhyolite. These are smoky gray on fresh fracture and have phenocrysts of quartz, sanidine, and wisps of biotite, in a flow-banded glassy matrix. No plagioclase is ordinarily to be seen with a hand lens in these rocks and even in thin section, but rare individuals are found. These rocks are true rhyolites.

AGE AND CORRELATION

The S O volcanics appear definitely younger than the period of thrust faulting that affected the rocks of the Dragoon Mountains. Near Outlaw Mountain they rest on an erosion surface cut on the Gleeson quartz monzonite. These outcrops are within a mile or so of the major fault that separates the imbricate pile of Paleozoic and volcanic rocks to the east from the Gleeson quartz monzonite block to the west. This western block no longer carries any except engulfed fragments of the thick Paleozoic section represented in the thrust pile. Accordingly the volcanic rocks are not only younger than the thrust faulting, but probably considerably younger; for a period of erosion sufficiently long to have much reduced the relief ensued after the faulting and before the volcanic rocks were deposited. As the thrust faults probably date from the early Tertiary, the S O volcanics are probably not older than Miocene.

Placing an upper limit on the age of the formation is equally indirect. North of Stockton Hill and the Reeves Ranch, the volcanic rocks are unconformably overlain by a fanglomerate, not distinguished on the map from other fanglomerates and unconsolidated alluvium of definite Quaternary age, but nevertheless older and perhaps Pliocene in age. This fanglomerate, which is exposed beneath the terrace cappings on the west side of the Dragoon Mountains at least as far north as South Pass, consists of pebbles and boulders of S O volcanics, limestone, quartzite, and Gleeson quartz monzonite, with the volcanic debris dominant in the lower part and the nonvolcanic becoming more abundant upward. It is tilted and locally has dips of 10° or 12° in directions so diverse that the dips cannot reasonably be explained as primary. No fossils have been collected from these beds, and their age is not known. However, younger gravels and conglomerates unconformably overlie them and are themselves truncated by the basaltic plug in Walnut Gulch just east of Tombstone. This plug is planed off, along with the adjacent conglomerates, by the terrace gravels of the Tombstone pediment. Accordingly, a fairly active history has supervened the eruption of the S O volcanics, and it does not seem likely that all these events could have been compressed into Quaternary time. A Pliocene, and probably an early Pliocene age, seems an upper limit for this volcanism.

HORNBLENDE ANDESITE PORPHYRY PLUG

A plug of hornblende andesite porphyry is incompletely exposed in the pediment about 1½ miles northeast of Outlaw Mountain, NW¼ sec. 18, T. 20 S., R. 25 E. The hornblende andesite porphyry here protrudes through a thin cover of alluvial gravels and crops out over a nearly circular area about 2,000 feet in diameter. The exposure is limited on all sides by alluvium except for a short distance along the southeast border, where some older conglomerate and shale of probable Tertiary age is poorly exposed along the contact. It is clear that the porphyry injects this older sedimentary series.

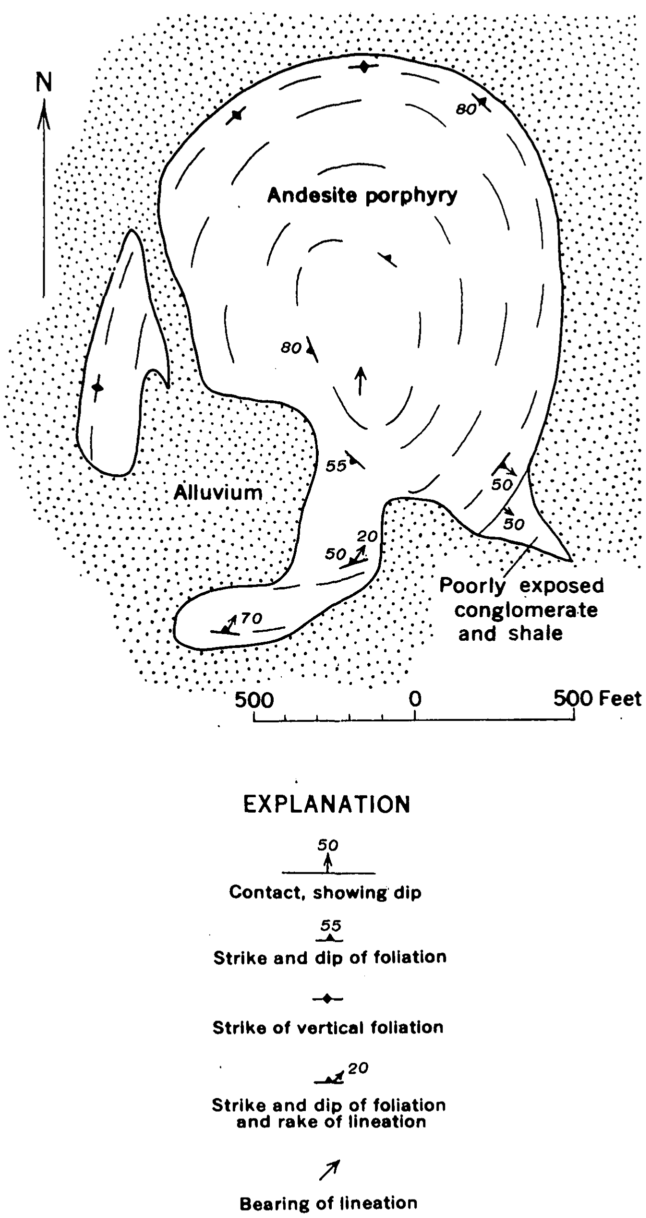

FIGURE 6.—Sketch map of hornblende andesite porphyry plug in NW¼ sec. 18, T. 20 S., R. 25 E.

The interpretation of this body as a plug is rather confidently made because of the well-marked steep peripheral flow structures displayed in it. (See fig. 6.)

The rock composing the plug is light gray, weathering to light brownish hues. Small vesicles are found throughout. Splendant crystals of green hornblende up to 1 centimeter in length are conspicuous in the border facies, but in the interior they are absent. Crystals of plagioclase 0.5 millimeter in diameter are sparsely distributed throughout the body. The groundmass is aphanitic. In thin section, the border facies is seen to be composed of hornblende, pleochroic in green and brown; augite, in granules that rarely exceed 0.1 millimeter in diameter; considerable magnetite; andesine, also in minute prisms; and a little orthoclase. The andesine is arranged in a radiate pattern, not pilotaxitic as would be expected from the notably parallel arrangement of the hornblende prisms. A little calcite and chlorite indicate slight alteration of the andesite porphyry.

The central facies of the plug is essentially the same as the border facies except that hornblende is lacking. There are ghostlike outlines of former hornblende crystals, now replaced by granules of augite and abundant octahedra of magnetite. Doubtless the alteration of the hornblende occurred in the volcanic neck because of escape of volatiles from the magma column.

The rock constituting this plug is very similar to that making up the andesitic members of the S O volcanics. Inasmuch as the flow alinement of the hornblende crystals of the S O volcanics in the areas to the south and west of this plug trend approximately toward the plug, it seems very probable that this plug is one of the sources of these flows.

QUARTZ LATITE PORPHYRY DIKES

Many narrow dikes of quartz latite porphyry and of quartz latite cut the Gleeson quartz monzonite in the area between Hay Mountain and Gleeson. None are large enough to show on the accompanying map without exaggeration. The rocks composing these dikes are not crushed, though they have been altered somewhat by hydrothermal solutions. They are light gray, almost white on weathered surfaces; and some contain phenocrysts of quartz and sanidine, along with a few flakes of biotite or chlorite pseudomorphic after biotite. Others are wholly aphanitic. Under the microscope the dominant minerals seen are quartz and potash feldspar, with subordinate plagioclase (now highly sericitized) and a little biotite or chlorite. The alteration has been generally sufficient to obscure the original textural relations, and the rocks show no characteristics that intrinsically relate them to any of the other igneous bodies of the area. The absence of cataclastic features implies that they are younger than the deformation of the enclosing Gleeson quartz monzonite and as the Sugarloaf quartz latite seems to have antedated this deformation, the most likely related rocks are the quartz latites of the S O volcanics. The dikes are therefore provisionally assigned to the epoch of the S O volcanics.

PEARCE VOLCANICS

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The rocks here named the Pearce volcanics form a group of conspicuous isolated hills rising above the alluvium of Sulphur Springs Valley in the neighborhood of Pearce, from which the group name is derived. Six Mile, Pearce, and the Sulphur Hills; Township and Three Sisters Buttes; and Turkey Creek Ridge are all composed mainly of these rocks. Most of these hills rise abruptly, with steep, craggy slopes, from the alluvium of the valley. The Bisbee formation is exposed in the lower slopes of the hills that straggle northeastward from Township Butte, and the overlying volcanic rocks stand in marked relief above.

STRATIGRAPHY

Within the map area, the base of the Pearce volcanics is exposed only in the hills east and northeast of Township Butte. At the west end of the hill in the north center of sec. 1, T. 18 S., R. 25 E., hornblende andesite forms the basal member of the Pearce volcanics and rests unconformably on the Bisbee formation. Within a few hundred feet toward the east, however, the andesite is overlapped by rhyolite which rests on the Bisbee formation for about a mile to the southeast, as far as exposures extend. In the hills just to the north, in sec. 36, T. 17 S., R. 25 E., rhyolite also overlies the Bisbee formation directly.

In most of the other exposures of the formation, the rhyolites either overlie the andesites or are in fault contact with them, notably on Six Mile Hill, Pearce Hill, Turkey Creek Ridge, and the southeast end of the Sulphur Hills. However, farther northwest, along the Sulphur Hills, a strip of rhyolite appears to be beneath the lowest exposed member of the andesite, though it is not well enough exposed to exclude the possibility that it is in fault contact. Whether or not this rhyolite is in normal stratigraphic position below the andesite, there are several lenses and one thick member of andesite included in the rhyolite series farther north and northeast. Accordingly, it seems clear that although most of the andesite is older than the rhyolite of the Pearce volcanics, its eruption continued into the epoch of rhyolitic volcanism.

The following is an incomplete section of the Pearce volcanics as measured in the Sulphur Hills, from a point in the NE¼ sec. 18 to the NE. cor. sec. 7, T. 17 S., R. 26 E.

Partial section of the Pearce volcanics

	Feet
1. Rhyolite, dark-purplish-gray, weathers lighter gray, massive, quartz and sanidine phenocrysts and a little biotite, in a glassy groundmass	200±
2. Tuff, rhyolitic, a few thin rhyolite flows; tuffs, thin bedded (average 3 inches), light gray, weathers gray brown; the flows, 2 to 4 feet thick and glassy	540
3. Rhyolite, massive flows, phenocrysts of quartz and subordinate sanidine up to about 2 millimeters long, in a glassy, pinkish-gray groundmass that weathers bluish gray	520
4. Rhyolite agglomerate, composed of blocks of pinkish rhyolite as much as 20 centimeters in diameter, in an aphanitic to glassy groundmass of gray rhyolite that weathers chocolate brown; becomes coarser toward the base, in erosional contact with member 5	230
5. Tuff-breccia, contains blocks of scoriaceous obsidian, andesite, and rhyolite, as much as 4 feet in diameter, in a pumiceous matrix; becomes finer grained upward	35
6. Tuff, water-laid, weathers brown to tan; contains, near the base, rounded pebbles of andesite and rhyolite about 5 centimeters in diameter, in a matrix of well-rounded grains; sorting poorer upward; large fragments of pumice occur in beds ½ to 2 feet thick; much impregnated with sulfur	250
Erosional unconformity, cuts out underlying member within about 1,000 feet toward the northwest.	
7. Olivine andesite, dark-gray, weathers reddish brown; contains prominent phenocrysts of feldspar up to 3 millimeters long, pyroxene and olivine up to 1 millimeter long, in a lithoidal, flow-banded groundmass; contains several zones of scoria that presumably mark flow boundaries	250
8. Rhyolite, much sanidine and subordinate quartz as phenocrysts, about 2 millimeters long, in an aphanitic to glassy groundmass; mottled reddish gray at the base, becomes uniform gray in middle and nearly white in upper part; strong flow structures	250
9. Hornblende andesite to feldspathic andesite, some sulfur-impregnated andesitic sand at base; hornblende crystals larger in higher flows, where they attain 3 centimeters in length; much feldspar present in the phenocrysts, groundmass is aphanitic but lithic; probably several flows represented	380
Total	2,655±

Base poorly exposed but probably rests on rhyolite, to judge from the float.

Inasmuch as neither top nor bottom of the formation is seen in this section, 3,000 feet is probably a minimum thickness for the formation in the Sulphur Hills. Probably not more than about half this thickness is to be seen in any other continuous exposure of the volcanic rocks within the map area. The upper limit of the formation throughout the map area is simply the overlap of the alluvium, and as the volcanic rocks have been highly deformed, it is impossible to estimate the maximum original thickness.

PETROGRAPHY

The andesitic parts of the Pearce volcanics are mostly normal flows, though there are subordinate flow breccias and a few thin water-laid andesitic tuffs. The flows are light pinkish gray to dark gray and weather to rather dark brown. Most specimens show phenocrysts of both plagioclase and hornblende. The plagioclase phenocrysts only locally exceed 1 millimeter in length and are commonly about 0.5 millimeter long; the hornblende crystals, which usually show hematitic borders recognizable with a hand lens, range in length from about 1 millimeter to as much as 3 centimeters. In some rocks the hornblende phenocrysts have been so much resorbed as not to be readily recognized in hand specimens. Augite occurs as phenocrysts in many specimens; and olivine, in a few; the crystals are about 1 millimeter long. The groundmass is aphanitic and commonly shows flow structures.

In thin sections no other phenocrysts are determinable. The hornblende is seen to be highly resorbed and in many specimens is represented only by rims of hematite around a central core of chlorite. The augite is commonly fresh though the olivine, where present, is almost wholly altered to chlorite or serpentine. The plagioclase is chiefly labradorite, ranging in composition from about An_{70} to An_{55}, but in a few specimens the border zones of the phenocrysts are as sodic as An_{45}. The groundmass feldspars, as is to be expected, are somewhat more sodic: about An_{50} to An_{40}. Augite, but no hornblende, is commonly present in the groundmass. Subordinate orthoclase has been found in the groundmass of some specimens, but plagioclase is the overwhelmingly dominant mineral in all. Near the Commonwealth mine, on Pearce Hill, and in a few other localities, the rocks are highly altered; and the dark minerals are represented by chlorite, epidote, and carbonates, and the feldspars, by sericite, epidote and carbonates.

The rhyolites include thick, massive flows, flow breccias, agglomerates, and tuffs, with the fragmental rocks probably predominant. The flows range from light pinkish gray through pink to purplish and weather dark brown. They are commonly glassy, with spherulites and lithophysae as much as 8 centimeters in diameter present in some of them. A few flows are lithic, and some are porphyritic black obsidian. Flow structures are generally prominent. Quartz and sanidine occur as phenocrysts in all the specimens examined, though they range greatly in relative abundance, from perhaps 10 to 1 dominance of one to the reverse relationship. In many rocks no other phenocrysts occur, but some from Six Mile Hill, Pearce Hill, Three Sisters Buttes, and the north part of the Sulphur Hills contain a little recognizable plagioclase. A few flakes of biotite also can be seen in some specimens, though most of that recognizable with the hand lens is in the pyroclastic members.

Quartz, sanidine, and commonly a little oligoclase can be recognized as phenocrysts in thin sections of the flow rocks. In some of the glassy rocks none of the groundmass is crystalline, but in most of the rhyolites the groundmass contains small crystals of these same minerals, along with a little biotite, feldspathic spherulites, and trichites. One or two specimens contain a few microscopic crystals of hornblende. Sericite and chlorite occur in some of the altered specimens. Nearly all the rocks examined have much glass in the groundmass.

The flow breccias and agglomerates seem to be composed of the same rhyolite as the massive flows.

The tuffs are generally lighter colored than the flow rocks and are mostly light gray to practically white on fresh fractures. They weather, however, to hues as nearly dark brown as the flows, though exceptional outcrops are nearly white even though weathered. Phenocrysts recognizable in these rocks are the same as in the flows except that biotite is commonly identifiable in hand specimens. In thin sections most of these rocks show no other minerals. They are mostly normal tuffs, but some show collapsed shards and devitrification textures that suggest that they might be welded tuffs.

Some of the water-laid tuffs in the Sulphur Hills are altered, with chalky feldspars, and are also highly impregnated with sulfur.

SOURCE

None of the original constructional forms of the volcanic landscape at the time of eruption of the Pearce volcanics are now recognizable. In fact the volcanic rocks have been highly folded and faulted and deeply eroded, so that their present distribution is a very insufficient clue to their former distribution. Perhaps the notable amounts of sulfur in the formation in the Sulphur Hills may indicate nearness to solfataric activity and thus probable nearness to the source of the volcanic rocks. No other clue, however, has been recognized.

RELATION TO OTHER VOLCANIC FORMATIONS

The Pearce volcanics are one of several formations of this region, each of which contains both andesitic and rhyolitic members. The basis for distinguishing these rocks from the others is wholly petrographic. The rhyolites differ from the quartz latites of the Sugarloaf in having much sanidine and only subordinate plagioclase as phenocrysts (the reverse relation prevails in the Sugarloaf); the plagioclase of the Sugarloaf quartz latite is generally andesine, where fresh, though in the Pearce rocks it is oligoclase; biotite is prominent as phenocrysts in the Sugarloaf rocks, whereas it is all but absent in the Pearce suite, except in small amounts in the groundmass.

If the andesites east of South Pass, here referred to as pre-Bisbee in age (p. 68), are really a part of the Sugarloaf sequence, as may perhaps be true, the absence of andesite from the Sugarloaf sequence no longer constitutes a difference between the two sequences. However, the andesites themselves appear to differ and thus to strengthen the distinction suggested by the siliceous members of the two formations. It is true that both hornblende and plagioclase occur as phenocrysts in both groups of andesitic rocks, but augite is more abundant than hornblende in the Pearce rocks, though the rocks east of South Pass contain no signs of it.

Comparison with the S O volcanics suggests that these two suites are also distinct. Hornblende crystals are essentially the only phenocrysts in the andesites of the S O volcanics; the andesites of the Pearce volcanics generally contain a smaller proportion of hornblende and considerable plagioclase and augite among the phenocrysts. The plagioclase phenocrysts of the andesites of the Pearce suite are generally more calcic than An_{50}, and the groundmass feldspars are between An_{40} and An_{50} in composition; that in andesites of the S O volcanics is generally near An_{35}. The Pearce rocks also contain no hypersthene, which is common in the groundmass of the andesites of the S O volcanics. The siliceous rocks of the two formations also differ in that the Pearce suite consists mostly of truly rhyolitic rocks with sanidine, quartz and oligoclase as phenocrysts, and very subordinate amounts of biotite, whereas the S O volcanics contain andesine phenocrysts (more abundant than those of sanidine), quartz, and considerable biotite, and are more properly classed as quartz latite. The distinction between the two suites is thus thought to be warranted, though of course, they may be of essentially the same geologic age.

GILA CONGLOMERATE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

Large areas in the San Pedro Valley are occupied by Quaternary gravels covering pediment surfaces. South of Boquillas River, on the west side of the valley, and south of Walnut Gulch on the east, these Quaternary gravels mask nearly all the valley floor, though a few exposures of underlying silts and gravels can be seen in some of the stream valleys that dissect the pediments near the river. To the north, however, although the lower pediment is generally well developed, the incisions by stream valleys are more abundant and deeper, so that rocks underlying the Quaternary gravels are widely exposed. These preterrace rocks (Gila conglomerate) are chiefly weakly consolidated sandstones and clays, and they form badlands where the terrace gravels have been stripped, or are exposed in steep slopes on the sides of terrace remnants that are capped by ledges of terrace gravels. No attempt was made during this survey to separate the Gila conglomerate from the Quaternary gravels in mapping, but the Gila must be exposed over an area of 15 or 20 square miles and clearly must underlie most of the valley beneath the pediments.

Scattered exposures of conglomerate older than the highest Quaternary pediments are found in many gulches, not only near the San Pedro River but also near the uplands. One of the larger continuous exposures is northeast of the Reeves Ranch, where fanglomerate is exposed at and below the level of the highest pediment over an area 5 or 6 miles long and as much as 2 miles wide. Many smaller exposures occur in the dissected country immediately east of Tombstone. In the whole Sulphur Spring Valley drainage area examined during this survey, the only exposure of rock referred to the Gila conglomerate is in the gulch west of Hay Mountain, where a tilted conglomerate is seen in the cut bank beneath the surface gravels.

STRATIGRAPHY

The rocks referred to the Gila conglomerate in the axial part of the San Pedro Valley are essentially flat lying, though somewhat disturbed by faults, especially in the neighborhood of Benson. The basement upon which they were deposited is not exposed, but a thickness of fully 500 feet can be seen in the dissected terraces, and doubtless a considerable further thickness lies beneath the valley floor. Near the central part of the valley the rocks are rather fine grained and include interbedded sandstone, siltstone, clay, fresh-water limestone, and some water-laid volcanic ash. Away from the river the whole section is somewhat more coarse grained, and conglomerate layers are present; at distances greater than 5 or 6 miles it is dominantly conglomeratic. The series was not studied in detail, but I have a distinct impression that more dark-brown and maroon beds exist in the neighborhood of Benson than farther south. Channelling of the darker beds to depths of several scores of feet can be seen in the dissected pediment west of St. David. These channels have been filled by conglomerate of lighter gray tones, so that possibly more than one period of deposition is represented by these rocks: an older period in which the darker series was deposited and a younger period in which the lighter colored series was laid down. Both series, if there are indeed two, have been truncated by the Quaternary terrace gravels.

The rocks referred to the Gila conglomerate northeast of Reeves Ranch are fanglomerate, which rests upon an irregular topography, with local relief measured in many scores of feet carved across the Gleeson quartz monzonite, Pinal schist and S O volcanics. The general dip of the fanglomerate is northwesterly at angles that range up to 12°, but this is clearly not the original dip—as is shown by some fine-grained interbeds that could not have been formed on any such slope—and it is locally reversed, with southeasterly dips as steep as 10°. Generally, however, the lower parts of the series are exposed along the eastern contact, the higher to the west.

The lower part of the fanglomerate contains unusually large boulders—many 5 feet in diameter—that locally include quartz monzonite or schist but are chiefly composed of hornblende andesite derived from the middle member of the S O volcanics. These predominate, not only along the southern part of the exposure, where the S O volcanics are close at hand but far to the north of South Pass. Toward the west and stratigraphically higher, grade size gradually changes from boulders to cobbles and then to pebbles, and the mutual proportions of the several rock varieties in the fanglomerate also changes. The hornblende andesite boulders become subordinate to boulders derived from the siliceous lower member of the S O volcanics, and pebbles and cobbles of quartz monzonite increase in relative abundance. In the western exposures quartz monzonite pebbles predominate over those of quartz latite, which are themselves more abundant than those of hornblende andesite. This is precisely the sequence that might be expected if the fanglomerate represents the deposit of material stripped from a block like that now seen to the east, which still contains residua of the S O volcanics but chiefly exposes quartz monzonite at the surface. Formerly the volcanic rocks must have blanketed this block to a thickness of several thousand feet and extended many miles farther north than now.

The fanglomerate contains a few thin layers of andesitic flow-breccia and travertine, but for the most part it is a coarse clastic deposit which becomes better bedded and of smaller grade size upward. It is buried along the western border by younger gravels in marked structural unconformity. The relief of the contact surface amounts to perhaps 50 feet in 200 feet of contact. It is probable that these younger gravels are truncated by the highest terrace gravels of the San Pedro Valley (belonging to the Tombstone pediment, later described) and hence are pre-Pleistocene. Possibly it is these younger gravels beneath the Tombstone pediment that should be correlated with the finer grained beds (here regarded as Gila) in the axial part of the valley rather than the older fanglomerate just described. But the disturbance of the finer sediments shows local deformation in Gila or post-Gila time, and perhaps both series may be correlated with the Gila conglomerate. The pediment gravels prevent tracing either of the two conglomerate series to a connection with the deposits in the central part of the valley.

Immediately north and east of Tombstone, Walnut Gulch and its southerly tributaries have dissected the Quaternary pediment and expose conglomerates of two series. The younger conglomerate, whose bedding seems nearly conformable with the terrace surface, is probably considerably older than that surface; for although the thickness exposed in the stream cuts is only a few score feet, drilling has shown that the conglomerate is at least 700 feet thick just north of town; and the contact between it and the bedrock in the mining area is a fault that is not topographically expressed. The pediment is developed indifferently to the bedrock across this fault. Possibly the gravels beneath the pediment are of early Quaternary age, though they may correlate with the Gila conglomerate.

Beneath this conglomerate, of doubtful but pre-pediment age near Tombstone, is an older conglomerate exposed on only a few places in the stream valleys. This conglomerate is composed of pebbles of hornblende andesite derived from the S O volcanics, along with others from the Bolsa quartzite, Bisbee formation, and limestone formations of the Paleozoic. It is associated with maroon mudstone, yellow-gray sandstone, and a little fresh-water limestone. The series dips as much as 20° in some of its small exposures and is clearly unconformable beneath the younger conglomerate just described. It must be of late Tertiary age and may, like the fanglomerate northeast of the Reeves Ranch, correlate with the Pliocene Gila conglomerate near Benson, or may be slightly older. These rocks are not distinguished on plate 5.

In the Sulphur Spring Valley an outcrop west of Hay Mountain is tentatively referred to the Gila conglomerate. This outcrop exposes about 80 feet of conglomerate, sandstone, and siltstone. The beds dip westward at about 25°, nearly parallel to the dip of the upper member of the S O volcanics, which forms the dip slope of Hay Mountain to the east. The conglomerate contains rounded cobbles of the quartz latite of this volcanic member, along with pebbles of limestone of Paleozoic age and sandstone of Mesozoic age, and is therefore probably disconformable on the nearby quartz latite. These rocks are unconformably overlain by gravels accordant with the general surface slope and are thus thought to be pre-Quaternary. It must be admitted that their correlation with the Gila conglomerate is wholly conjectural, though their ages must be roughly the same. Near Courtland in the SE¼ sec. 16, T. 19 S., R. 25 E., is an outcrop of fanglomerate resting on Colina and Horquilla limestones. The rock is well consolidated and has been disturbed, but its attitude is obscure, except that it clearly passes beneath the present valley gravels. It contains boulders as much as 5 feet across of Bolsa quartzite, mudstone of the Bisbee, monzonite porphyry, rhyolite, and several kinds of limestone. It does not appear to have been involved in the thrusting of the nearby area. It, too, may perhaps be better correlated with the Gila conglomerate than any other formation locally recognized, but no positive evidence favors this.

AGE AND CORRELATION

The Gila conglomerate was named by Gilbert (1875, p. 540–541) from exposures in the Gila Valley above the mouth of Bonita Creek, about 100 miles northeast of this area, near the New Mexican border. As pointed out by Knechtel (1936, p. 81–92), the deposits described by Gilbert include lakebeds and marginal fanglomerates of the Gila and San Simon Valleys.

Within the area of this survey, fossils have been collected from two localities by Kirk Bryan and J. W. Gidley. According to Gidley, those from near Benson, on the west side of the river, are of late Pliocene age; those from a point 3 miles east of the Curtis School on the east side of the valley (about 12 miles SSE. of Benson) are perhaps upper Pliocene, but may be early Pleistocene (Gidley, 1922, 1926; Gilmore, 1922; Wetmore, 1924). The collections from the southern locality are definitely somewhat younger than those from near Benson, and, in fact, the two have no species in common. It is possible that two distinct sedimentary series may be represented in the two collections, for as mentioned above, deep channeling and filling is locally evident. However this may be, the correlation suggested by Knechtel (1936) seems sound, and the rocks in the central part of the San Pedro Valley seem clearly correlative, both in age and manner of deposition, with those at the type locality of the Gila conglomerate. The stratigraphic descriptions point out the uncertainty of whether the fanglomerate near South Pass and the Reeves Ranch is of the same age as the rocks from which these collections were made; they may be older but probably are upper Tertiary, and for convenience they are here classed with the Gila conglomerate. The same considerations apply to the older of the two conglomerate series near Tombstone and to the isolated sedimentary rocks beneath the pediment west of Hay Mountain and near Courtland.

OLIVINE BASALT

On the Gleeson Highway about three-fourths of a mile northeast of Tombstone is an irregular mass of olivine basalt about half a mile in diameter which has been described by Butler, Wilson, Rasor (1938, p. 28) as a probable ring dike, surrounding a core of altered cemented conglomerate. This mass was not examined in detail during this survey, but it was noted that the volcanic rocks have been reduced to the level of the gravel terrace in this area and the mass is in part overlain by the terrace gravels. Although the sedimentary gravels injected by the basalt are almost certainly of late Tertiary age, no flow rocks or other remnants of any surficial volcanism from this vent have been seen anywhere in the vicinity. The time that has elapsed since the injection of this mass and prior to the formation of the surrounding terrace clearly must have been enough to permit the complete erosion of not only higher parts of the intrusion, which must certainly have existed, but also of any ejecta or flows from this center. The dike (not shown on pl. 5) near Grand Gulch cuts the Bisbee near the Bunker Hill mine and strikes roughly toward this center and is probably contemporaneous with the injection of this mass. If so, it seems necessary to assume erosion of several hundred feet of rock in the intervening country in order to account for the difference in elevation between the central mass and the present outcrop of the dike.

Other exposures of olivine basalt have been noted at two widely separated places in the area of this survey. A few small dikes were seen cutting the Bronco volcanics just west of the railroad, about half way between Contention and Fairbank. These dikes do not cut the valley gravels, but inasmuch as the local gravels are probably as young as the terrace gravels near Tombstone, it is still possible for these dikes to be of the same age as the probable ring dike on the Gleeson road. On the other hand, nothing indicates that these western dikes may not be far older than the eastern. In the NW¼ sec. 25, T. 20 S., R. 24 E., about a mile south of Outlaw Mountain, basalt is exposed in low mounds rising above the valley gravels which must here be merely a thin veneer on the pediment. The rock forming these mounds is a highly vesicular olivine basalt, resembling the rock of the ring dike near Tombstone much more than it does the porphyritic basalt of the nearer locality at Sugarloaf Hill. Exposures are not sufficient to ascertain whether these patches of basalt are parts of a flow or of an intrusion.

QUATERNARY DEPOSITS

GENERAL FEATURES

Quaternary deposits of the area include pediment gravels that cover large parts of the San Pedro Valley, colluvium in small parts of the mountainous area, and alluvium that occupies most of the Sulphur Spring Valley and considerable parts of the northern San Pedro Valley trench. These deposits have not been distinguished on the map, either from each other or from the rocks referred to the Gila conglomerate; and attention given them has been only incidental to other work. The discussion following is largely based upon reconnaissance physiographic maps prepared by Kirk Bryan,[9] who generously made them available for this report. A reduced copy of his reconnaissance map of the Benson quadrangle is reproduced as plate 10.

These deposits are all younger than the upper Pliocene deposits of the San Pedro Valley referred to the Gila conglomerate, because even the highest pediments transect the bedding of the Gila. Inasmuch as no fossils have been found in any of these deposits and the relation of these deposits to climatic cycles which might furnish some clues as to age has not been worked out, it is impossible to state which of these deposits may be Pleistocene and which Recent. They are accordingly described in the following pages according to their areal distribution and sequence within the two major drainage basins.

SAN PEDRO VALLEY

In the San Pedro Valley two pediments, called by Bryan the Tombstone (higher) and Whetstone (lower), can be readily recognized, in addition to the Recent (Arivaipa, of Bryan) trench and flood plain of the river. Southeast of Brookline a few low hills rise above the surface of the Tombstone pediment, but except for them, most of the valley surface west of the river and south of the latitude of Boquillas is formed by this pediment, which has been dissected, but only by narrow trenches. East of the river the Tombstone pediment forms most of the surface south of Walnut Gulch. Wide headward extensions into the Tombstone Hills have divided them into isolated masses. The dissection of the Tombstone pediment in this area is nearly restricted to the valleys of the present streams, and the Whetstone surface is very slightly developed as mere stream terraces, except near Lewis Springs, where it is about 1½ miles wide. At Lewis Springs the Tombstone pediment surface is at about 4,100 feet, the Whetstone at 4,050, and the Arivaipa surface at about 4,030; 2 miles south of Fairbank the altitudes of the 3 surfaces are, respectively, about 4,000, 3,900, and 3,850.

From Walnut Gulch nearly to Slavin Gulch on the east side of the river, the Tombstone pediment can be recognized east of the river; but here it is much dissected, and long and wide tongues of the Whetstone pediment are developed. These are in turn dissected by trenches of the Arivaipa epicycle. North of Boquillas on the west side of the valley and north of Curtis School on the east, the Tombstone pediment is only represented in small remnants, if at all; and the lower, Whetstone, pediment forms most of the surface, though much dissected by trenches of the Arivaipa epicycle. At a point a mile from the river and southwest of the Curtis School, the most northerly point at which the Tombstone pediment appears on Bryan's map, this surface is at 3,900 feet; the Whetstone pediment, about 3,800 feet; and the Arivaipa flood plain, about 3,710 feet. At Benson the Tombstone pediment has been destroyed; here the Whetstone pediment stands at about 3,650; and the flood plain of the river of the Arivaipa substage, about 3,500 feet.

Wherever the pediment surfaces have been dissected and exposures are good, it can be seen that the gravels that cover them range in thickness between 2 and perhaps 20 feet. These gravels are locally well cemented by caliche but are clearly derived from higher parts of the surfaces still preserved. In general, the deposits of the Arivaipa epicycle are sandy in the tributary valleys but relatively silty in the flood plain of the San Pedro River.

SULPHUR SPRING VALLEY

Whitewater Draw, the axial stream of the Sulphur Spring Valley, flows between low alluvial banks that blend almost imperceptibly into the smooth bajada slopes leading up to the mountains on either hand. Farther north the drainage courses into Willcox Playa are even less definite along the axis of the valley. The alluvium in the central parts of the valley is largely sandy with some silt, is wholly unconsolidated, and obviously related to the present erosion cycle. The tributary streams from the Dragoon Mountains somewhat dissect the bajada slopes as the mountains are approached, both those that drain to Whitewater Draw and those toward Willcox Playa. The bajada sediments have thus been trenched to depths of 40 or 50 feet near the Cowan Ranch house and to comparable depths near Courtland, Walnut Spring, and Stronghold Canyon. The sediments thereby exposed are all related to the present surface and, though locally well cemented, must be of Recent age. As might be expected, they are somewhat coarser grained near the mountains than in the valley floor but are generally

[9] Bryan, Kirk, manuscript maps of Benson and adjoining quadrangles, showing major physiographic divisions.

somewhat finer grained than the sediments on surfaces of comparable slope in the San Pedro drainage. Possible explanations of this difference are discussed in connection with the geologic history of the area.

UPLAND AREAS

Except for narrow belts of alluvial gravels along most of the stream courses, the only Quaternary deposits of the uplands are small talus cones and rock slides, nowhere of noteworthy dimensions. These accumulations are all so small that they have been neglected in mapping, though they locally obscure important relationships of the bedrock units.

STRUCTURE

GENERAL STATEMENT

This section treats the structural evolution of the area under four main headings: Pre-Cambrian deformation, Post-Paleozoic–pre-Cretaceous deformation, Post-Comanche–pre-Pliocene deformation, and deformation associated with, or younger than, the Gila conglomerate. In a broad way this organization is of course chronologic, but the relative dating within the third of these groups, when the greatest deformation occurred, is largely arbitrary because so many of the rocks are nonfossiliferous.

The structures discussed under the first heading, the pre-Cambrian, are obscure and principally represented by folds of east or northeast trend, locally modified by igneous injection. Those under the second are represented by broad folds, batholithic intrusion, and faults in the Mule Mountains and parts of the Dragoon Mountains. Undoubtedly many structures other than the few here recognized as belonging to this epoch were actually formed during this episode, but the intense deformation during post-Comanche time has obscured them.

The major deformation of the area took place in post-Comanche time. The abundant thrust faults of the Dragoon Mountains, the minor thrusts of the Tombstone Hills and Mule Mountains, and innumerable smaller faults and drag folds associated with these were formed at this time. The thrust faults fall into two groups: one with dominantly easterly trends, the other with north or north-northwest trends. The faults of the first group are clearly recognized only in the Mule Mountains and Tombstone Hills; those of the second are found in the Tombstone Hills and Dragoon Mountains. The northward-trending faults seem definitely to have the greater displacement, though accurate measurement is impossible. It is more than likely, in fact all but demonstrable, that there was a considerable age difference between the formation of the structures of these two trends, with the folds and faults of east trend the older. Some eastward-striking folds were planed off and the Bronco volcanics were deposited during the interval between them. Perhaps the eastward-trending structures are middle Cretaceous in age, and the northward-trending, post-Cretaceous. (See p. 160.)

The northward-trending faults seem to involve "structural ungluing" of the Paleozoic and Mesozoic rocks from the basement, with repetition of thin thrust slices at and near the base of the Comanche. Presumably the piling-up of these thrust slices raised the cover of Comanche rocks into a huge anticline, with a syncline to the east. After this anticline had risen high enough to override the eastern syncline, the high-angle Dragoon thrust broke through it and overturned the western limb of the syncline along the eastern side of the present Dragoon Mountains. The travel involved in this high-angle thrust is not known, but apparently it need not have been very great, perhaps a few miles. Toward the south of the Dragoon Mountains the thrust has a transcurrent section where it apparently overrode the southward-plunging syncline of Comanche rocks completely. Southward from this segment, a gigantic thrust breccia rests on the Comanche and younger volcanic rocks in the Courtland and Gleeson area.

The Stronghold granite, younger than this major compression, was apparently emplaced largely by stoping, though it may also have bowed its roof rocks upward for a few hundreds or thousands of feet. Clearly this bowing was wholly inadequate to supply the space now occupied by the intrusion.

Volcanic and minor sedimentary rocks younger than the thrusting have been deformed along irregular axes; probably their deformation was caused by local adjustments to magma movements beneath, rather than to regional deformation.

The present mountainous areas are almost surely set off from the valley areas by normal faults of the Basin and Range system, but such faults are poorly exposed and cannot be systematically followed. They may, in fact, be lacking along the east side of the Dragoon Mountains, though they are locally exposed on the west side and have been found by drilling in the Tombstone district. Evidently motion on these faults has long since ceased, perhaps in early Pleistocene time, for the widespread pediments transect them.

The structures attributed to each of these epochs of deformation are treated in the following more detailed descriptions.

PRE-CAMBRIAN DEFORMATION

A period of pre-Cambrian orogeny is recorded in the structure of the Pinal schist. Scattered exposures, later deformation, and lack of distinctive beds suitable for mapping on the scale of plate 5 all combine to prevent working out the major structures of this formation; the generally northeast or east-northeast strike of the foliation, however, suggests that the pre-Cambrian orogenic axes trended in the northeast quadrant. Many exceptions to this strike were observed and are recorded on the map, and not all of them were seen in areas of later shearing, so that the pre-Cambrian deformation in this area was possibly in part characterized by steep tectonic axes or the attitude of the foliation reflects later folding of an originally more consistent structure. Nevertheless, the total impression is of a dominance of northeasterly trends.

In the Bisbee district, immediately to the south, Ransome (1904, p. 25) recorded his impression of a similar northeasterly strike of the foliation in the Pinal schist; this trend also prevails in the Aravaipa–Stanley area (Ross, 1925, p. 40) and in the Ray–Miami district (Ransome, 1919, p. 34). Lindgren (1905, p. 56) reported that the foliation in the Pinal schist of the Morenci district strikes generally east. These scattered observations over a considerable part of southeastern Arizona, though far from adequate for definite conclusions, suggest that the pre-Cambrian structural axes of post-Pinal age were nearly at right angles to the trend of the younger dominant structural grain of the region.

The several small intrusive masses (probably pre-Cambrian) that are found in the Pinal schist show no systematic structural relations from which either the mechanism of their emplacement or relation to other structures may be inferred.

POST-PALEOZOIC–PRE-CRETACEOUS DEFORMATION

In large parts of the area the rocks of Paleozoic and Mesozoic age are similarly deformed and in many places the contacts between the rocks of the two eras are faults. No criteria have been discovered in such areas for determining the pre-Cretaceous attitude of the Paleozoic rocks. In these localities the present structure of the Paleozoic rocks may either have been imposed wholly in post-Comanche time, or equally probably the post-Comanche deformation may have been superposed on pre-Cretaceous structures. However, wherever the basal contact of the Cretaceous rocks is depositional, considerable pre-Cretaceous deformation and erosion must be inferred.

As described in preceding sections of this report, the Comanche rocks rest in depositional contact upon rocks as old as the Pinal schist in the western Mule Mountains and upon various formations of the upper Paleozoic elsewhere. Even where there is structural conformity between the Cretaceous and the youngest preserved Paleozoic formation, the Epitaph dolomite, channeling and coarse conglomerate testify to considerable topographic relief. Furthermore, over wide areas, the basal conglomerate of the Bisbee group contains pebbles recognizably derived from the Pinal schist and Bolsa quartzite. In the Mule Mountains the Cretaceous rocks overlap onto coarse intrusive rocks of post-Paleozoic age, furnishing further evidence of strong orogeny, intrusion, and deep erosion during the interval between the deposition of the Epitaph dolomite and the beginning of deposition of the Comanche series.

In the northern Mule Mountains, shown on plate 5 near the southeast corner of the Benson quadrangle, the dominant pre-Cretaceous structure appears to be the northwestern limb of an anticline, the exposed part of which has a northeasterly trend and whose core has been injected by the Juniper Flat granite in pre-Cretaceous time. Slices of Paleozoic rocks upthrust through the Morita along the north foot of these mountains suggest that the Paleozoic rocks swing easterly beneath the Cretaceous and later deposits in a plunging nose. Though concealed by the Cretaceous overlap, this plunging nose must roughly coincide in plan with the present northern end of the mountains. In part then, the Mule Mountains are standing high because of a rejuvenation in post-Cretaceous time of a much older upfold or, if the essentially homoclinal structure of the Cretaceous be accepted at its face value, because of uptilting of a fault block that in part coincides with such an older upwarp. In the Bisbee area, however, Ransome (1904, p. 85–108, especially p. 92) showed that many of the pre-Cretaceous faults and broken folds have a northwesterly trend. Several faults of this trend extend into the area of this report: in Tombstone Canyon, in the southeast corner of the Benson quadrangle. These faults seem, however, subordinate in structural effects to the homocline in the rocks of Paleozoic age and serve to offset this major structure only a few hundred feet. The southwestern part of the Mule Mountains has not been mapped in sufficient detail to permit any confident interpretations as to which of these trends is dominant. In any event, the intrusion of the Juniper Flat granite may have produced local structures at variance with the regional trends of the pre-Cretaceous folds, so that it seems impossible to determine from the fragmentary evidence available what the regional strike of the deformation of this period may have been.

Indefinite as are the conclusions to be drawn from the known structure of the parts of the Mule Mountains thus far studied, the relations in the rest of the area are even less clear. For example, although the Bisbee formation is unconformable on the Epitaph dolomite in the Tombstone Hills, the angular discordance is not

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great. The unconformity seems generally to cut lower beds of the Epitaph dolomite toward the east, but the exposures are distributed in a practically linear rather than areal pattern and do not suffice definitely to outline the pre-Cretaceous structural trends.

Basal Cretaceous strata are not exposed in the southern part of the Dragoon Mountains, and all contacts with older rocks are faults. The present structural relations of the Gleeson quartz monzonite so clearly result from post-Comanche deformation that nothing can now be ascertained as to the conditions of emplacement or the relation of this intrusion to the tectonic axes of the post-Paleozoic–pre-Cretaceous orogeny. For the same reason, the relations during emplacement of the Turquoise granite and Copper Belle monzonite porphyry are also obscure. All of these intrusions, as now exposed, are believed to have traveled notably from the sites of their origin during the Dragoon thrusting.

In the central Dragoon Mountains, the Cochise Peak quartz monzonite is found in intrusive contact with pre-Cambrian rocks and rocks of early Paleozoic age only—all its other contacts are faults. In view of the probability that all these blocks were transported during deformation, no conclusions as to the intrusive relations of this formation or its place in the pre-Cretaceous orogenic framework of the local area can be drawn.

In the northern Dragoon Mountains the basal conglomerate of the Bisbee formation is exposed at many places in an area of several square miles, and rests on formations ranging from Escabrosa limestone (just north of Middle Pass) to Epitaph dolomite. These rocks are so strongly—practically isoclinally—deformed that the possibility of considerable bedding faulting cannot be excluded; the Paleozoic rocks of the area almost conform in attitude with the Cretaceous; and though the underlying beds are different from place to place, in general the pre-Cretaceous tilting of the rocks of the Paleozoic probably was not very great.

On the south side of Fourr Canyon the Bisbee formation rests in depositional contact on Colina limestone, Earp formation, and Horquilla limestone, and its basal contact shows no offset at a fault that throws Colina limestone against the Horquilla. This fault now trends generally north of east. It is surely pre-Cretaceous in age.

Farther east a synclinal body of Bisbee rocks about 2,000 feet long and 300 to 400 feet wide trends practically north from a point just west of the quadrangle boundary and about 1½ miles south of the north boundary of the area. Toward the south and along the entire western contact, this body of Bisbee rests on the Earp formation. However, at the north end it rests on Colina; and along the northern part of the eastern boundary, on Epitaph. The rocks here are isoclinal and considerably metamorphosed, but if these outcrops have been correctly interpreted, these relations indicate another pre-Cretaceous fault. Its trend, prior to the isoclinal folding of the Bisbee can not, of course, be determined.

Still other faults, to the east of the syncline just mentioned, appear to cut the Paleozoic rocks without offsetting the basal Cretaceous. One of these, about a mile north-northwest of Mount Glen, shown on plate 5 as not offsetting the Cretaceous rocks, may, however, actually do so and have escaped observation either because it parallels the isoclinal folds of the Cretaceous rocks or perhaps cuts the base at so narrow an angle as not to have been identified in the general shearing. The fault is therefore mapped as buried beneath the Bisbee although it is perhaps equally probable that the fault extends through the Bisbee but is obscured because it almost parallels the sheared-out synclinal limbs. The faults bounding the wedge of Horquilla and Epitaph extending about half a mile south of the common north corner of the Pearce and Benson quadrangles into the same mass of the Bisbee formation, for example, may extend much farther than they have been traced. The Bisbee to the east, however, rests at different nearby places on Epitaph dolomite, the Earp formation, and Colina limestone, in apparently normal deposition. The present exposures of Colina-Epitaph contacts at the Cretaceous overlap trend generally west of north. If account be taken of the post-Cretaceous shortening, it would be inferred that the pre-Cretaceous trend of the Paleozoic contacts was somewhat more westerly than the present. None of these features suggest structural relief in the Dragoon Mountains comparable to that in the northern Mule Mountains of pre-Comanche time.

As it has been impossible to determine the extent of travel of the thrust blocks within the Dragoon thrust belt and hence the original relations of the intrusive rocks among them to the Paleozoic rocks, an accurate reconstruction of the pre-Cretaceous geology is not feasible. In the blocks that preserve basal Cretaceous rocks, however, there is no indication of more than a few hundred feet of structural relief, except in the northern Mule Mountains. Over the region as a whole, the rocks of the Naco group are widely preserved, implying that pre-Cretaceous folding was not intense. On the other hand, the entire Paleozoic section, together with an uncertain but considerable thickness of Pinal schist and Juniper Flat granite, were eroded from the northern Mule Mountains prior to the encroachment of Comanche deposition. Similar deep erosion—implying comparable structural relief elsewhere in the wider region of which this is a part—is indicated by the cobbles and boulders of recognizable Bolsa quartzite in the conglomerates of the Bisbee formation throughout the whole area. Possibly some of these cobbles and boulders were derived from the areas represented by the blocks composed largely of intrusive rocks—Gleeson quartz monzonite, Cochise Peak quartz monzonite, Turquoise granite, and Copper Belle porphyry—whose original position can no longer be identified. Several of these formations invade rocks of Paleozoic age, and this necessarily implies structural disturbance. The distribution of the Comanche series suggests that some of the uplifted areas lay to the north, northwest, and west of the present area; at any rate, the shoreline of the Comanche sea lay in these directions.

POST-COMANCHE–PRE-PLIOCENE DEFORMATION

GENERAL STATEMENT

The dominant structural features of the area were formed in post-Comanche time. The deformation was complex, with many episodes whose details have not been completely worked out, though certain broad sequences of events may be discerned.

The dearth of post-Comanche fossiliferous rocks in the area renders impossible a truly chronological classification of the structural features formed during post-Comanche time. The major thrust faults locally furnish a means of relative dating of some structural events. A classification based on these features may, however, be far from chronological for the area as a whole. This is not simply an a priori probability but is based on the occurrence of thrust faults of widely divergent trends and hence probably attributable to more than one orogenic episode. Further, the widespread cover of younger volcanic and alluvial formations limits the exposures of the critical structures to small and discontinuous areas, so that most of the evidence for subdividing the evolutionary stages remains indirect.

In view of these facts, it seems desirable here to state simply that the structural episodes may be regarded as falling into four stages, as follows: Structural features older than the thrust faults, eastward-trending thrust faults and folds, north-northwestward-trending thrust faults and folds, and structural features younger than the thrust faults. Inasmuch as the sequence of thrusts has not been proved, however, and because an areal treatment of the structural features is less subjective than a chronological description based upon such uncertain postulates, the post-Cretaceous structures are described in the sequel according to the following scheme and main headings: Structural features older than the thrust faults, Thrust faults and associated structures, and Structural features younger than the thrust faults.

The first of these categories should perhaps include many structures elsewhere, but evidence sufficient to discriminate structures as older and apparently independent of the thrusting was recognized only in the northern part of the map area. Under the second of these headings, the treatment is by areas, beginning at the south. It should be noted that this organization of the discussion conforms to the chronological sequence if the east-trending compressional features actually antedate the northward- and northwestward-trending ones. The eastward-trending structures are best represented in the areas southeast of the Tombstone Hills. Within the Tombstone Hills are compressional structures of both trends, and it is here that suggestions of an age distinction between the two suites are most persuasive. On the other hand, the Dragoon Mountains exhibit chiefly folds and faults of the north-northwest system.

One other preliminary note is perhaps justified: the fact that eastward-trending folds are found in the southerly parts of the map area to the exclusion of northward-trending ones does not indicate that the southern limit of the northward-trending faults of the general region is to be found within the area here described. The Gold Hill thrust of the Bisbee mining district to the south (Ransome, 1904, p. 101–105) is probably closely comparable to the Dragoon thrust within this area. Accordingly, the absence of northward-trending post-Comanche folds and faults in the northern Mule Mountains most probably indicates merely a curvature of the fault belt. Faults of this trend are probably buried beneath the alluvium of either the Sulphur Spring Valley or the San Pedro Valley (or both?) in the southern part of the area shown on plate 5.

STRUCTURAL FEATURES OLDER THAN THRUST FAULTS

In and near Jordan and Fourr Canyons, in the northern Dragoon Mountains, there are several masses of granitic rock, cut by faults of which some are believed to be of the same age as the Dragoon thrusts. Though many of these masses are fault blocks, several exhibit well-exposed contacts against the schists of Cretaceous age. Despite the later shearing that has affected both formations, some of these contacts are so highly irregular as to strongly suggest that they are intrusive. Accordingly, the intrusions are considered post-Cretaceous and hence younger than the igneous cycle to which the Juniper Flat granite definitely, and the Cochise Peak quartz monzonite, Turquoise granite, Copper Belle monzonite porphyry, and Gleeson quartz monzonite less definitely, are assigned. The intense shearing that the intrusion and its wall rocks have undergone has destroyed any evidence of its original form or mode of emplacement.

The structural relations of the granite body in Ash Creek Ridge, about 10 miles east-southeast of Pearce, are poorly exposed, but give the impression of an anticlinal fold, with a granite core within a Cretaceous envelope. This suggests that the intrusion may be concordant and possibly laccolithic. The alluvium masks so much of the bedrock here as to make futile any further discussion of the possibilities.

These intrusive rocks imply a considerable deformation of their wall rocks at the time of their emplacement; indeed, it seems likely that they represent a late phase in a distinct orogenic cycle as granitic rocks commonly do elsewhere in the world. If they do indicate such a distinct cycle, the structures produced have been so much deformed in later time or are so much obscured by younger rocks as no longer to permit deciphering even their main trends.

South of Cochise Stronghold, the thrust faulting has been so intense that any older structures once represented are no longer recognizable. Many considerable areas are also masked by younger volcanic rocks and by alluvium. Structures that involve Cretaceous rocks and at the same time seem independent of the thrusting have not been recognized either in the Mule Mountains or Tombstone Hills.

THRUST FAULTS AND ASSOCIATED STRUCTURAL FEATURES

The structural axes and thrust faults of dominantly easterly trend are confined to the southern half of the area: Tombstone Hills, Mule Mountains, and intervening areas. If they were formerly present in the Dragoon Mountains, they have been so dissected by later thrusting and masked by younger formations as no longer to be deciphered. The Tombstone Hills also retain evidences of northward-trending faults. Faults and folds of north to northwesterly trend are dominant in the Dragoon Mountains. These structures are described in the following paragraphs by areas.

NORTHERN MULE MOUNTAINS

In T. 21 S., Rs. 22, 23, and 24 E., many of the hills expose eastward-trending structures, either faults or folds, that involve Cretaceous rocks. Sections illustrating these structures are nos. *XXIII–XXIII′*, *XXVI–XXVI′*, *XXVII–XXVII′*, *XXVIII–XXVIII′* and *XXIX–XXIX′*, of plate 6. (See also pl. 13.)

Perhaps the most interesting of these structures is best exposed in sec. 19, T. 21 S., R. 24 E. Several miles south of this fault zone, the Morita formation forms an essentially homoclinal block, the beds of which dip northeast at angles ranging from 3° to 10°. At about the latitude of Gadwell Spring, 2 miles south of the fault zone, the northeasterly dip gives place to more irregular attitudes and lower dips, so that one may interpret the structure as the axis of a poorly defined syncline. Disregarding any pre-Comanche relief of the surface of unconformity at the base of the Bisbee group, the strata exposed along this axial area are about 1,500 feet above the base of the Bisbee as exposed east of Sandy Bob Ranch. To the north of Gadwell Spring, the dips in the Morita are southward, at low angles; but about half a mile south of the fault zone, the dips become much steeper and at the fault become essentially vertical. Rough computation of the thickness exposed in this southward-dipping zone suggests that, if there had been no thickening of the Morita northeastward from Sandy Bob Ranch, its base should appear along the fault. Local slivers of conglomerate are exposed here, but they are obviously dragged blocks, for the unbroken parts of the Morita reveal no such coarse beds. It is concluded that the pre-Bisbee relief of the unconformity was considerable and that the Morita is notably thicker here than a few miles to the southwest. This is confirmed by the relations of the Morita strata exposed to the north of the fault zone, as described in a subsequent paragraph.

The southern fault of this fault zone is well exposed both in natural sections and in several prospect pits. It dips north at angles ranging from 40° to 70°. The Cretaceous rocks of the footwall are considerably sheared, and there are local slivers indistinguishable from the Glance conglomerate among the fault slices. The hanging wall of the fault is composed of rocks of Paleozoic age that range from Abrigo limestone to Horquilla limestone as the fault is followed westward and from Abrigo to Escabrosa toward the east. These Paleozoic rocks form a tightly appressed anticline, plunging both ways from the little stream in the SW¼ sec. 19. The belt of Paleozoic rocks ranges in width from about 1,000 feet to a knife edge, as it is followed to the east. Its northern boundary is formed by a second fault. As shown by several prospect pits, this fault also dips northward at angles of 45° to 70°, nearly parallel to the footwall fault. To the north of this fault the Morita is exposed, dipping southward at angles of 35° to 80°. The exposures are much interrupted by alluvial cover, but the tops of all the exposed Morita strata clearly face to the south.

The faults bounding the strip of Paleozoic rocks converge and must surely join at its eastern end. Exposures are not complete but suffice to prove that if one or both faults continue beyond the junction, it is for less than a thousand feet. Beyond that distance along the strike to the east, the Morita is well exposed in an unbroken steep fold, the beds of which swing abruptly upward from the axial part of the syncline to the south in a smooth arc of about 2,000 feet relief and then bend over, still unbroken, into a gentle northward-dipping homocline. This steep monocline, between gentle northward-dipping segments, continues eastward for about 1½ miles and then swings in a smooth arc southeastward to the alluvium bounding the Mule Mountains on the eastern side. It seems clear from these relations that this monocline is the structural homologue of the fault zone to the west.

Toward the west the faults pass beneath the alluvium in the valley south of Government Butte. A small sliver of Morita is exposed on the north side of this valley, pinching out to the west between two faults, the lower one with Escabrosa limestone in the footwall and the higher with Colina limestone in the hanging wall; westward from the junction of these two faults, the Colina overlies the Escabrosa for about 3,000 feet before the fault is concealed by alluvium. Further west, along the south base of Government Butte, the lowest exposed rocks are the Earp formation and Horquilla limestone. The Comanche rocks are not exposed, though they almost surely form the footwall of the concealed fault, as far as the west end of the Butte.

The interpretation of the structures just described seems to require rather novel assumptions. Taking the relations in sec. 19, T. 21 S., R. 24 E., at their face value, the south fault bounding the Paleozoic sliver is clearly a thrust, with rocks of Paleozoic age in the hanging wall resting on the Bisbee. The northern fault is normal, with Bisbee resting on Paleozoic and dipping into the fault plane. The relations are thus essentially those of a horst whose bounding faults have been tilted, so that both now dip northward. It seems unlikely, though, that this can be the true explanation of the relations, for the monoclinal upwarp along the strike extension to the east (pl. 13) indicates a sharp relative uplift along this line, with the rocks outside the arcuate trace of the monocline raised as a block about 2,000 feet with respect to those inside the arc. There seems little likelihood of explaining the relations by successive activity of the bounding faults, with, say, first a thrust with overriding from the north, followed by a normal fault within the thrust block; for this would make the simultaneous dying out of both reverse and normal fault at the same point appear entirely unlikely. It seems necessary to postulate the simultaneous activity of both of the bounding faults. This amounts to interpreting the block of Paleozoic rocks as forming a diapir structure, injected into the Cretaceous cover.

Under this hypothesis, it is difficult to account for the absence of drag in the Bisbee strata along the northern fault, especially in view of the extreme shearing that the Paleozoic rocks have undergone in the footwall of the same fault. The presence of these Paleozoic rocks in the thrust area, however, demonstrates that they were originally present beneath the Morita cover, implying that this is not far from their zone of overlap on the Pinal basement. Inasmuch as alluvium conceals most of the faulted anticline to the west, the interpretation of these relations is not subject to observational test. The following hypothesis, which is the one illustrated on plate 6, sections *XXVI–XXVI′* to *XXIX–XXIX′*, appeals to me as the best of the half dozen or more tested solutions of the enigma presented by this structure.

Prior to the deposition of the Bisbee group, the Pinal schist and the intrusions in it had been exposed by erosion of the overlying Paleozoic rocks from the area of the present northern Mule Mountains. The erosion left a ring of Paleozoic rocks that surround and dip away from the Pinal schist. The dip that the Paleozoic rocks had in this situation can no longer be determined; however, there is some suggestion that it was fairly steep. The shortening across the curving monocline extending eastward and southeastward from the fault belt can be readily computed as not more than 3,000 feet for much of its length, and though the shortening increased greatly to the west, the presence of the fault block of Paleozoic rocks seems to imply that the beds involved had already possessed a fairly steep dip beneath the gently tilted Cretaceous blanket prior to the thrusting. Such a steep dip would appear to be a necessary inference from the fact that a relatively small total movement could bring about the emplacement of the tightly appressed anticline of Paleozoic rocks through at least 1,000 feet of Cretaceous rocks. Whether the anticline was already present (at least as a minor flexure) before the thrusting cannot, of course, be determined. The assumption of such a flexure (pl. 6, secs. *XXVI–XXIX*) seems to lead to an economy of displacement on the thrust. It also seems to be suggested by the homoclinal structure of the Cretaceous to the northeast, for if the fold were entirely due to the thrust movement one might expect a wider disturbed zone in the Cretaceous blanket. In view of the widespread occurrence of faults along the shaly beds of the Paleozoic elsewhere in the region and the slight disturbance of the Cretaceous rocks away from the fault zone and monocline, it seems justified to attribute much of the fold and faults to bedding slip. (See pl. 6, secs. *XXVI–XXVI′* to *XXIX–XXIX′*.)

GOVERNMENT BUTTE

Along the south base of Government Butte (pl. 13), a series of faults are exposed, nearly along the strike of the fault zone just described. For the most part these faults are nearly parallel to bedding and bring younger formations over older. For example, half a mile east of the boundary between the Pearce and Benson quadrangles, the Escabrosa limestone crops out at the boundary of the alluvium. It strikes east, and the dip is vertical. The Escabrosa is overlain, on a north-dipping fault, by Horquilla limestone, which has a northwesterly strike and moderate southwesterly dip; the Horquilla is in turn overlain, on a flat fault, by Colina limestone whose attitude is disturbed and irregular but on the whole dips gently northerly. Both faults are concealed by alluvium to the east and west. What is presumably the northern one is seen again to the east, where the Colina above it rests on Escabrosa, the Horquilla having wedged out, while to the west it again appears with Colina in the hanging wall and the Earp formation exposed to the south as a narrow strip along the alluvium at the foot of the butte.

These stratigraphic changes in the footwall of the fault, with Colina overlying it, imply a movement of several thousand feet; for the Colina seems essentially conformable to the attitude of the fault.

Near the quadrangle boundary another fault appears from beneath the alluvium, duplicating much of the Earp formation. Toward the west it approaches the higher fault and in about a mile joins it. The structure here is confused by younger normal faults (not all of which are shown on the map), and the mapping is further complicated by topographic irregularities. However, the fault at the base of the Colina can be traced down the southwest flank of the butte where it passes beneath the alluvium with a southwesterly strike and a dip of 15°–20° NW. Throughout this distance the hanging wall is Colina limestone. Except for about 1,000 feet, the footwall is Earp formation, but a lower fault crops out in an arc tangent to the upper one and brings Horquilla limestone directly against the upper fault (and thus against Colina limestone) for a short interval. Of course, whether this lower arcuate fault is the same that brings Horquilla over Escabrosa a mile and a half to the east is uncertain, as alluvium masks the intervening area.

There are several normal faults of generally easterly trend on both the north and south flanks of Government Butte. None of these have stratigraphic throws larger than about 800 feet. Their age is entirely unknown, except that they are post-Cretaceous, but their parallelism in strike to the thrust faults suggests they may be genetically related to the thrusts, perhaps being slightly younger.

EARP HILL

The structure of Earp Hill (pl. 13). resembles that of the western part of Government Butte. The trends are generally east; there is evidence of a northward-dipping thrust fault that locally cuts out part of the Earp formation and elsewhere duplicates it. This I have interpreted as essentially a bedding thrust, connected in origin with a sharp fold in the Horquilla limestone. The displacement, being so nearly conformable to the bedding, is difficult to evaluate and cannot be measured; I have provisionally assumed it to be only a few hundred feet, and it is so represented on plate 6, section *XXVI–XXVI′*.

As in Government Butte, normal faults, of the same general trend, consistently drop the southern blocks with respect to the northern blocks they separate. These faults have stratigraphic throws of 200–300 feet.

TOMBSTONE HILLS

GENERAL STATEMENT

The structure of the Tombstone Hills is complex, and the stages of its development cannot readily be discriminated, despite the fairly complete exposures. The folds and faults are far from systematically arranged, and the interpretation of the sequence of their formation is ambiguous. As noted in the local descriptions following, the relations in some places permit or even suggest the interpretation that some of the northward-trending structures were formed before some of the eastward-trending, though the evidence for this is not conclusive. Because of these ambiguities, it seems desirable to describe all the major sturctural features together, reserving for a subsequent paragraph the discussion of their age relations. Accordingly, the following descriptions pertain to northward-trending, eastward-trending, or oblique features of the Tombstone Hills, though it is recognized that some are chronologically distinct from the eastward-trending faults and folds of the northern Mule Mountains, Government Butte, and Earp Hill. The conclusion may here be anticipated that it seems possible to interpret the history in terms of most of the eastward-trending structures being older than most of the northward-trending, though there may have been renewed adjustments of the eastward-trending folds and faults during the formation of the northward-trending and oblique features.

TOMBSTONE SYNCLINE

The mining district of Tombstone is largely in a syncline (pl. 13) of the Bisbee formation, through which a few erosional inliers of Epitaph dolomite crop out. The axis of the main syncline trends nearly west and plunges gently eastward. It is complicated by many smaller but tightly appressed folds that trend generally north of west, as described in detail by Butler, Wilson, Rasor (1938, p. 28–38).

This syncline, with Cretaceous rocks in the core, exposes vertical to northward-overturned beds of the Horquilla, Earp, and Colina formations along its south flank, where it is cut off by the Prompter fault. It is cut off on the west by the northward-trending Ajax fault, which is in turn cut by the Schieffelen granodiorite. The synclinal axis abuts sharply against the granodiorite mass, which is clearly younger than the folding.

PROMPTER FAULT

The Prompter fault (pl. 13), a steep reverse fault, strikes nearly east through the southern part of secs. 15, 14, and 13, R. 22 E., and secs. 18 and 17, R. 23 E., T. 20 S., and separates the Tombstone syncline from the Ajax Hill horst. As exposed in mine workings, the dip of the fault is 60° to 80° south. Its stratigraphic throw is about 3,000 feet near the common boundary of secs. 14 and 15, T. 20 S., R. 22 E., increasing to as much as 4,000 feet toward the west and diminishing to about 1,500 feet a mile farther east. The Prompter fault (or at least some of the movement along it) is younger than the Schieffelen granodiorite as was pointed out on p. 104.

AJAX HILL HORST

The block to the south of the Prompter fault has been called the Ajax Hill horst (pl. 13) by Butler, Wilson, and Rasor (1938, p. 30–32); relations of this block to the surrounding ones are complex; it seems best to outline the salient features of the block itself before considering them.

The horst occupies about 6 square miles, chiefly in secs. 22, 23, 24, 25, 26, and 27, T. 20 S., R. 22 E. It is bounded on the west by the Ajax fault, which trends nearly north at the western base of Ajax Hill; on the north by the Prompter fault; and on the south by the Horquilla Peak fault. Toward the east its boundaries are concealed beneath the alluvium.

A northward-trending anticline, with its axis near the boundary between secs. 22 and 23, lies along the western side of the horst. This fold exposes Pinal schist and pre-Cambrian intrusive rocks along its axis. The anticline plunges northward, so that Cambrian rocks are nearly continuously exposed across the axis in the faulted area just south of the Prompter fault. These Cambrian rocks form the western part of the horst on the north.

The eastern limb of the northward-trending anticline, as expressed in the outcrop of the Escabrosa-Horquilla contact about a mile to the east of the axis, is essentially straight except for small cross faults. Dips along this contact average about 50° E. Toward the east, in the Horquilla limestone, the dips rapidly flatten, and in secs. 24 and 25 the principal structure is a westward-plunging anticline (with a double nose) as expressed on plate 15 by the contact between the Escabrosa limestone and lower Horquilla. This structure trends slightly north of east.

AJAX HILL FAULT

The western boundary of the Ajax Hill horst is formed by a northward-trending fault, here called the Ajax Hill fault (pl. 13). This fault, which in its exposed sections dips eastward at high angles (Butler, Wilson, and Rasor, 1938, p. 31), is occupied for more than a mile of its course by a dikelike body of Uncle Sam porphyry ranging in width from 300 to 1,000 feet. Both walls of the dike show frozen contacts, and there can be no doubt that the dike is younger than the great fault. It separates Cretaceous (and an overlying thrust block of Colina limestone and Epitaph dolomite) on the west from Cambrian and pre-Cambrian rocks on the east. The porphyry diverges from the fault in the northern part of sec. 22; and for about half a mile farther north, the Bolsa quartzite on the east abuts directly against the Bisbee formation. The stratigraphic throw here is at least 5,500 feet. In section 15 the Ajax Hill fault is offset by at least four branches of the Prompter fault, in each instance with the north wall offset westward; and finally, 2,000 feet north of the Prompter fault, it is cut by the Schieffelin granodiorite and cannot be traced further.

HORQUILLA PEAK FAULT

The south side of the Ajax Hill horst is formed by a normal fault whose strike is about N. 65° E. and whose dip is about 60° SE. It is here named the Horquilla Peak fault (pl. 13) because of its outcrop on the south side of Horquilla Peak. This fault has several branches with displacement in the same sense and brings beds high in the Colina limestone against beds low in the Horquilla, a stratigraphic throw of nearly 2,000 feet. Some of the branch faults bring Epitaph dolomite down against the Colina in the hanging wall of the main fault. Toward the west the Horquilla Peak fault cuts off the northward-trending anticline of rocks of early Paleozoic age and its core of Pinal schist, though, by coincidence, the ridge of Escabrosa limestone which is so conspicuous a feature of the horst is continued in a comparable ridge of Epitaph dolomite and Colina limestone directly in strike with it to the south.

SOUTHEASTERN SPUR OF HORQUILLA PEAK

Horquilla Peak lies at the junction of three ridges: the Military Hill ridge to the north in the Ajax Hill horst, Colina Ridge to the south, almost in line with this but trending slightly more to the west of south; and a third ridge, trending about S. 50° E., that extends almost to a junction with Earp Hill, to the east of the Tombstone-Bisbee road. This southeast ridge is a strike ridge about 2½ miles long formed by steeply tilted beds of the Colina limestone with locally Epitaph dolomite on its dip (northeastern) slope. A thin segment of Earp formation occurs on the southwest slope for about a mile and shows, in common with most other outcrops of this weak formation, considerable evidence of bedding faulting. In view of the fact that the northwestern spur of Earp Hill lies essentially in line with this ridge and shows closely comparable structure, it is likely that this spur owes its structure largely to the same orogenic episode as the small thrusts of Earp Hill.

HILLS IN T. 20 S., R. 23 E.

Due east of Horquilla Peak is a valley bounded on the north by the tilted beds along the Horquilla fault and on the south by the dip slope of the southeastern spur of Horquilla Peak just described. This valley is the western end of a syncline trending east and widening in that direction, though obviously not plunging in this direction, for the Cretaceous and Epitaph rocks of the core are at the western end of the fold. The southern limb must be faulted, though the faults are concealed by the alluvium; otherwise, the Epitaph dolomite should be exposed much farther eastward than it is. The hills that lie in this syncline are separated from each other and from the main Tombstone Hills by alluvium, so that all their relations are obscure. In general, however, they consist of Colina limestone, with gentle folds along eastward-trending axes. Several sill-like bodies of rhyolite occur, along with small patches of Epitaph dolomite in downwarps. Toward the east the Earp formation crops out along the crest of a low faulted anticline. The faults that dissect this generally synclinal group of hills are probably considerably younger than the folding. The folds, because of their generally easterly trends, are regarded as congenetic with the eastward-trending thrust faults.

COLINA RIDGE

Colina Ridge (pl. 13) extends south-southwest from Horquilla Peak, though the rocks composing it are cut off by at least two faults from those of the Ajax Hill horst. The ridge is an eastward-dipping homocline, exposing the Horquilla limestone and Earp formation at its western base, the Colina limestone on its western slope and crest, the Epitaph dolomite and locally the Bisbee formation on its eastern (dip) slope. There is no evidence of any eastward-trending structures within the 2 miles of its length.

AREA EAST OF BRONCO HILL

Most of the structures of the Bronco Hill and Lewis Springs area, at the south end of the Tombstone Hills, are connected with the north-northwestern fold trend or with local intrusions. However, in the area of Bisbee outcrops about a mile due east of Bronco Hill and 2½ miles north of Lewis Springs, the rocks stand in nearly isoclinal folds with east-west axes and steep, practically vertical, or even overturned limbs. In several places steeply plunging anticlinal noses, closing to the west, were observed. The lack of marker beds and the scale of mapping prevented detailed elucidation of this structure, if it is, indeed, feasible. However, these folds are clearly not far from the projected strike of the fault zone along the south side of Government Butte; and despite the several miles of concealed area between, the possibility that they represent a continuation of the zone is by no means remote.

As described in connection with the stratigraphy of the Bronco volcanics, the steep structures in this area are not reflected in the base of that formation; clearly a considerable period of erosion supervened between the folding and the deposition of the volcanic rocks.

AREA WEST OF AJAX HILL HORST

A belt of Cretaceous rocks, with subordinate areas of Uncle Sam porphyry and rocks of late Paleozoic age, lies between the Ajax Hill horst and the main mass of Uncle Sam porphyry that forms the western Tombstone Hills. This belt is about a mile wide and extends north of the latitude of the horst in a belt of about the same width, between the Schieffelin granodiorite on the east and northeast and the Uncle Sam porphyry on the west and southwest. North of The Three Brothers hills it narrows to only a few hundred feet.

The Bisbee formation in this belt is highly irregular in structure. During this survey no detailed work was done here because of the larger scale mapping by Ransome (Butler, Wilson, and Rasor, 1938, pl. 3), but the few observations made indicated such variable attitudes that no synthesis of the structure is attempted. Neither does Ransome's mapping permit an unambiguous generalization.

Despite this unsatisfactory situation, several pertinent observations may be recorded. At least three outliers of an overthrust of rocks of late Paleozoic age rest on the Bisbee formation. The largest of these is about half a mile long and consists of Colina limestone and Epitaph dolomite. It lies just southwest of Ajax Hill and is separated from the Ajax Hill horst by a great, high-angle fault now followed by a dike of Uncle Sam porphyry, frozen to both walls and hence definitely younger than the fault. About a thousand feet west of this outlier is a much smaller one of Epitaph dolomite, also in contact with the porphyry. This porphyry mass also seems frozen to the dolomite. Many sills and dikes of porphyry occur in the neighborhood, and none are sheared or cut by other than trivial faults. Accordingly, these thrust blocks were clearly emplaced before the intrusion of the porphyry. The third fault outlier is a small block of Colina limestone at the contact of the porphyry north of The Three Brothers hills. This is only a few hundred feet wide and perhaps 1,500 feet long and also rests on highly disturbed beds of the Bisbee formation. For more than a mile to the southeast of this block, the porphyry lies against a highly disturbed breccia—not distinguished from the Bisbee formation on the map—that consists of blocks of limestone of Paleozoic age and of sandstone, shale, and conglomerate of the Bisbee, all highly sheared. This breccia is cut by shear surfaces dipping southwestward beneath the porphyry. The porphyry itself shows no such deformation.

These facts seem to demonstrate that the thrust fault recorded by the outliers of Paleozoic rocks on the Bisbee is older than the intrusion of the porphyry, as is also the fault bounding the Ajax Hill block on the west. It has been suggested elsewhere (Gilluly, 1945, p. 661–665) and on p. 100 that the Uncle Sam porphyry occupies a thrust plane, in part. That it is younger than the thrusting seems quite certain in view of its chilled contacts against the several thrust outliers mentioned.

INTERPRETATION OF STRUCTURAL FEATURES OF TOMBSTONE HILLS

The large-scale structural features of the eastern Tombstone Hills have been described in the preceding paragraphs. Their interpretation, both in terms of the sequence of their origin and the crustal forces operative in their production, seems both uncertain and ambiguous. As a possibility for more detailed future consideration, the following hypothetical interpretation is suggested, though it is recognized that other hypotheses equally accordant with the observed relations may probably be offered. The present suggestions, however, require fewer shifts in the orientation of tectonic axes from time to time during the structural evolution of the area than others that have occurred to me.

FIRST STAGE—NORTH-SOUTH COMPRESSION

During the first post-Comanche deformational period, the rather gentle folds of east trend were formed, along with considerable bedding slip and possibly minor thrust faults such as are now exposed on the southwest side of the southeast spur of Horquilla Peak and on the south side of Earp Hill. It is assumed that at this time the trends of the folds were essentially east and that the present eastward plunges were developed later. The minor thrusts were east in strike and dipped north at low angles. The isoclinal folds of easterly trend east of Bronco Peak were formed at this time. They constitute a record of the more intense deformation along this southern line of folds which farther east is represented by the thrust belt at the south side of Government Butte.

SECOND STAGE—EROSION AND REDUCTION OF THE OLDER TOPOGRAPHY

This stage is recorded in the unconformity at the base of the Bronco volcanics east of Bronco Hill. If this has been correctly interpreted, it seems likely that a considerable interval of time elapsed between the north-south and east-west compressional episodes.

THIRD STAGE—EXTRUSION OF THE BRONCO VOLCANICS

The thickness of the Bronco volcanics shows that they were formerly much more widespread than at present. The formation must have originally extended over the entire area of the Tombstone Hills. Its present generally westerly dip conforms roughly with the attitude of the segment of the thrust fault north of The Three Brothers hills, where it is cut off by the Uncle Sam porphyry, and to the gentle westward dip of the fault surface beneath the thrust remnants southwest of Ajax Hill. Two possible interpretations of the present relations occur to me: the Bronco volcanics may have been involved in the thrusting (of northwest trend), in which event their removal from the eastern Tombstone Hills may be explained by both faulting and later erosion; or the thrust may have antedated the Bronco volcanics, which buried the thrust plate and have since been removed entirely by erosion. There is no place in the area studied in which the Bronco volcanics and the northwestward-trending fault are in contact, and I have been unable to determine any compelling reason to accept one of these interpretations as more likely than the other.

Perhaps favoring a prethrust age for the Bronco are the facts that the tilting of the thrust fault and Bronco are about the same and both dips are homoclinal in the block west of the Ajax Hill fault. There are reasons, discussed in subsequent paragraphs, for assigning the Ajax Hill fault to the period of the thrusting, so that it might be contended that this relation supports a prethrust age for the volcanic rocks. On the other hand, the petrographic similarity between the quartz latite member of the Bronco volcanics and the Uncle Sam porphyry might be significant of their comagmatic origin. If they were, indeed, derived from the same magma, it is unlikely that the epoch of volcanic eruption could have been separated from the epoch of intrusion of the porphyry by so long a time as would permit the formation of the thrusts. This would suggest a postthrust age for the Bronco volcanics. Their removal from the eastern Tombstone Hills would thus be explained by block tilting and erosion of the uplifted eastern areas. This would make the present rough parallelism between the general dip of the volcanic rocks and thrust fault a mere coincidence. Inasmuch as the Ajax Hill fault has been inactive since its injection by the Uncle Sam porphyry (as shown by the frozen contacts and absence of brecciation of the porphyry within it), this would imply that the westward tilting recorded by the present general attitude of the Bronco volcanics affected areas to the east of the Ajax Hill fault as well. There is no suggestion of any partial reversal of a formerly steeper dip of the beds in the Ajax Hill horst or the adjoining blocks to north and south. Accordingly, this interpretation seems slightly less probable than a prethrust age for the volcanic rocks. Nevertheless, it should be recognized that, at least in my opinion, the assignment of a prethrust age to the volcanic rocks is a matter of convenience rather than demonstration.

FOURTH STAGE—SOUTHWEST-NORTHEAST COMPRESSION

During this stage strong compression along southwest–northeast lines produced thrust faults of northwesterly trend and the Ajax Hill fault and associated structures.

The thrust remnants attributable to thrusts of northwesterly trend within the Tombstone Hills are areally almost insignificant: a short segment on the north side of The Three Brothers hills, cut off in both directions by undisturbed Uncle Sam porphyry, and two small outliers of rocks of late Paleozoic age resting upon the Bisbee formation southwest of Ajax Hill. Both of these outliers are also cut by the Uncle Sam porphyry. The position of the easternmost outlier requires a horizontal component of the thrust movement of about a mile and a former extent still farther eastward is indicated by the cutting-off of the thrust by the Ajax Hill fault. Although this transection of the thrust by the high-angle Ajax Hill fault might suggest that this fault is younger than and unconnected with the thrust, there are strong evidences that the Ajax Hill fault is a compressional feature and may therefore have been formed during the same epoch of compression as the thrust, though of course at a somewhat later stage.

Among the evidences of compression along the Ajax Hill fault, perhaps the most convincing are the relations within the Ajax Hill horst, though several minor features elsewhere along it are consonant with this interpretation. As noted in the description of the Ajax Hill horst, the western part of the horst is occupied by a closely appressed anticline striking nearly north. This is at right angles to the somewhat gentler folds of the eastern part of the horst and suggests that the anticline is younger than these easterly folds farther east. As shown in plate 6, section *XVII–XVII′*, the shortening across this anticline, as measured by the fold of the Bolsa quartzite at its north end, amounts to about 3,000 feet. If the rocks of the fold were straightened out, the western boundary of the block would fall almost exactly into line with the Ajax Hill fault north of the Prompter fault. This strongly suggests that the Prompter fault is a flaw or transcurrent fault that formed simultaneously with the anticline and permitted the differential adjustment of the eastern side of the Ajax Hill fault, with the formation of the anticline on its southern side while the northern side was less crumpled.

North of the Prompter fault the Ajax Hill fault dips eastward at 70°; to the south of the segment occupied by porphyry, it dips steeply westward (Butler, Wilson, and Rasor, 1938, p. 31). The disturbance of the rocks along the Ajax Hill fault, though pronounced, does not seem sufficient to permit the assumption that it is a folded thrust—the fault would indeed have to be overturned in part and such overturning would imply considerably more intense deformation in the area than is indicated. Accordingly, it seems more reasonable to regard the Ajax Hill fault as having formed in the region in front of and below the thrust, owing to partial shearing off of the basement ahead of the thrust and squeezing up of the block on the east.

Easterly tilting of the east side of the fault is indicated by the uplift of the anticline within the Ajax Hill horst; it is also consistent with several other features. Among these, the easterly plunge of the Tombstone syncline, though it could perhaps be a primary result of the essentially north–south compression recorded in the general area, is perhaps better explicable by a subsequent uplift of the western part of the structure by tilting along the Ajax Hill fault, because there are similar eastward tilts farther south. Similarly, the northwesterly strike of the strata forming the spur extending southeast from Horquilla Peak, with its exposed northeastward-dipping bedding faults and minor thrusts, is exactly what could be expected if these faults originally had easterly strikes and gentle northerly dips (as their eastward continuations in Earp Hill now have) and the block immediately east of the Ajax Hill fault were tilted strongly to the east and simultaneously uplifted. The second tilt would produce the present geometrical relations which otherwise seem inconsistent with the adjoining structural trends. Such a tilt and uplift would also explain the attitude of the beds in Colina Ridge, south of the Horquilla Peak fault, directly on strike with the homoclinal ridge of the Escabrosa limestone to the north of the fault. Although the eastnortheast-trending Horquilla fault might perhaps be simply a normal fault, rather than a transcurrent fault like the Prompter, it should be mentioned that the relations along it are not inconsistent with horizontal displacement.

Still another suggestion that the easterly tilt along the Ajax Hill fault was superposed upon previous eastward-trending structures is given by the syncline east of Horquilla Peak. The deepest part of this syncline is near the western end, although the easterly divergence of its exposed limbs would suggest an easterly plunge. If the tectonic axis of this syncline were originally nearly horizontal and endwise compression and uplift of the western part took place later, as here postulated, it is easy to visualize the local downwarping of the axis to produce the anomalous relations now found.

The interpretation outlined implies, as has been pointed out, that the Prompter fault is a flaw, or transcurrent fault, along which the dominant motion has been horizontal. This is strongly suggested by the presence of the Ajax Hill anticline south of the Prompter fault and the absence of any comparable east–west shortening to the north of it. It is furthermore supported by the marked easterly offset of the Ajax Hill fault on the south side of each of the several branches of the Prompter fault. The Ajax Hill fault is steep, probably steeper than 70° on an average; and the offsets shown, if produced by dip-slip movement on the Prompter fault, would require displacement of much greater amount than the stratigraphic throw of the faulted branches would indicate. On the other hand, if the movement were dominantly horizontal, as postulated, there is close agreement with the stratigraphic throw and with the shortening indicated by the Ajax Hill anticline. Furthermore, several of the branches of the Prompter fault have the relations of feather joints, conforming with a relatively easterly displacement of the south side of the fault.

It should be pointed out again, however, that the Prompter fault offsets dikes probably related to the Schieffelin granodiorite, of postthrust age. These offsets are uniformly smaller than those of associated steep contacts of other formations, and at least one dike has been mapped by Butler, Wilson, and Rasor (1938, pl. 4) as cutting a branch of the fault without offset. Accordingly, it seems reasonable to evaluate the offsetting of the dikes by the Prompter fault as due to later minor adjustment along it, rather than as proving the entire displacement to be younger than the emplacement of the Schieffelin granodiorite.

The evidence for horizontal movement along the Horquilla fault, on the south side of the Ajax Hill horst, is much less convincing than for the Prompter fault. This may be because of poorer exposures of the Ajax Hill fault in the junction area with the Horquilla Peak, for it is entirely uncertain as to whether the Ajax Hill fault is offset here as it is by the Prompter. If the net slippage of the Horquilla fault was essentially horizontal, it must have been in the opposite sense to that along the Prompter; that is, the north, rather than the south, side was displaced relatively to the east. Such a displacement seems to explain the position and stratigraphic composition of the rocks in Colina Ridge more readily than a dip-slip movement, but it cannot be said to be demonstrable.

DRAGOON MOUNTAINS

GENERAL STRUCTURE

The exposed structural features of the Dragoon Mountains are much more complex than those of any other area in the region considered during this survey. (pl. 13.) The dominant elements composing the mountains are rocks of Paleozoic age and Cretaceous sedimentary and pre-Cretaceous intrusive rocks, cut by many thrust faults of north to northwest strike and later invaded by the Stronghold granite.

Along its trend the range may be conveniently divided into six segments, in each of which the exposed structural elements differ from those adjoining. Beginning at the north, these are north of Cochise Stronghold, Stronghold granite area, Cochise Stronghold to Middle Pass, Middle Pass to South Pass, South Pass to North Courtland, and Courtland–Gleeson area.

The large mass of Gleeson quartz monzonite forming most of the range proper south of South Pass may be considered another structural unit; its internal structures have, however, no obvious relation to those of the adjoining areas, and no observations useful to the elucidation of the major tectonic features have been gleaned from it.

The general structure of each of these segments of the range is briefly outlined in the following paragraphs. Later sections discuss the individual structural features in more detail.

From Cochise Stronghold to the north edge of the mapped area, there is a succession of closely folded rocks, cut by folded thrusts, steep reverse faults, and flat thrust faults, the whole indicating overriding from the west. The metamorphism of the country rocks by the Stronghold granite has been superposed upon the already complex structure, and many of the distinguishing lithological features of the individual formations have been obscured and the faults healed by metamorphic minerals. The metamorphism and the complexities of the structure combine to render the interpretation of many areas rather subjective—nevertheless it is possible to establish the major features with a fair amount of confidence.

To the south of this area of complex structure lies the main mass of the Stronghold granite, which has not caused noteworthy local deformation, but did apparently bring about a broad gentle doming of the roof, with respect to comparable structural horizons to the north and south.

Between Cochise Stronghold and South Pass the dominant structural features are folded and imbricate thrust sheets, many of which now dip eastward, cut by the clean Dragoon thrust, of fairly steep west dip. The Cretaceous area to the northeast of the mountains shows marked disturbances related to the Dragoon thrust. Toward the north the Bisbee formation dips steeply only along the fault and flattens to moderate northeastward dips a few thousand feet to the northeast; farther south the Cretaceous section is overturned for several miles across the strike—in places with overturned dips of 35° SW. The zone of such overturned dips widens southward, strongly suggesting an overturned syncline of southerly plunge that probably passes below the thrust plane to the southeast of South Pass.

Near South Pass the rocks of Paleozoic age and pre-Cambrian rocks of the thrust sheet give place to the Gleeson quartz monzonite, which constitutes nearly all the overriding mass of the Dragoon thrust to the south and southeast. The thrust bounding this block swings abruptly eastward at a point a short distance south of South Pass and, accompanied by a complex belt of schuppen structure made up of steeply dipping and highly sheared Paleozoic rocks, trends nearly east for more than 3½ miles. This eastward-trending zone has the geometrical relations appropriate to a flaw—a transverse break in the thrust sheet that is perhaps localized by the plunge of the overturned syncline in the Cretaceous rocks to the north. This east-trending segment possibly marks a zone across the strike of the Dragoon fault, to the south of which the southward plunge of the Cretaceous syncline permitted the Dragoon thrust or its precursory flat thrusts to emerge on the erosion surface. It is also possible that this swerve may have been influenced by the form of the Gleeson quartz monzonite mass. Such a monolithic mass might well have reacted differently than the bedded rocks or the fissile Pinal schist during the thrusting.

In the northeast corner of sec. 18, T. 19 S., R. 25 E., the trace of the fault that bounds the block of Gleeson quartz monzonite turns abruptly south. At the angle between the transcurrent part of the fault and the southward-striking segment, the quartz monzonite has been brecciated and locally reduced to mylonite for several hundred feet from the fault. The relations just south of the corner strongly suggest a fairly low westerly dip; for two apparently small faults, which cannot be traced across the narrow block of intrusive rocks, permit the exposure of Bisbee formation in a reentrant in the fault plane about 1,000 feet back of the general front of the fault block. The low dip suggested by this reentrant probably accounts for the wide zone of brecciation and mylonitization in this area—a feature to be expected if the exposed levels of the thrust block are only a short distance above the fault. If the fault dip inferred from these observations is indeed relatively low, it is only a local feature. Farther south the trace of the fault in the topography indicates a steep dip. Actual exposures of the fault are very poor, owing to the much altered character of the adjacent rocks, the weakness of the zone against weathering agents, and the consequent accumulations of colluvium along it.

The Courtland and Gleeson mining districts lie just to the east (in front) of the Dragoon fault in this southern segment. The geological structure in these districts is extremely complex, and true representation is impossible on a map of the scale of plate 5. The enlarged map of plate 11 is also much too small in scale to permit portrayal of any but the gross features of the structures. In general, however, it may be said that the dominant structural features of these districts are a series of low-dipping thrust sheets, in complex sequences of superposition. Along the Dragoon thrust these thin thrust sheets are bent upward to relatively steep easterly dips. These thin thrust slices thus antedate the last movement on the steep Dragoon thrust, if indeed, they do not belong to a considerably older series of overriding thrusts which have been cut off by the development of the Dragoon thrust beneath them. This is perhaps suggested by the presence of similarly eastward-dipping thrusts north of South Pass where they lie not in front of the Dragoon thrust sheet but on top of it. Consideration of the minimum displacements along these thrusts indicates that they represent far-travelled masses. The present steep dip of the Dragoon thrust through most of the area seems to suggest so much less travel that it appears necessary to postulate later development of the Dragoon thrust beneath older flatter sheets. Thus, though all the sheets were presumably formed during a single orogenic cycle, the Dragoon thrust is probably considerably younger than the thin flatter lying sheets which it appears to have cut and dragged to steeper angles.

AREA NORTH OF COCHISE STRONGHOLD

(Pl. 6, secs. *I-I'*, *II-II'*, *III-III'*)

GENERAL FEATURES

Scattered exposures along the northwest base of the Dragoon Mountains north of the Fourr Ranch indicate that the Stronghold granite underlies the surface at a relatively shallow depth. This interpretation is supported by the metamorphic character of the rocks along the mountain front. The alteration of the several formations present is such as to mask many of the characteristics that in less metamorphosed facies enable their ready discrimination. It has already been remarked that in the areas of intense metamorphism surrounding the Stronghold granite the Bisbee formation is only with difficulty distinguished from the Pinal schist, and similar difficulties have been encountered in discriminating between the several formations of late Paleozoic age. For this reason, and because of the complexities of the structure, which are far greater than can be shown on the scale of plate 5, the mapping in this general region is probably less satisfactory than elsewhere. Nevertheless, despite certain possible inconsistencies in details, the general features of distribution of the formations and tectonic units are thought to be essentially as depicted.

From Mount Glen northward the crest and eastern flank of the Dragoon Mountains expose tightly folded anticlines and synclines of rocks of the Naco group and Bisbee formation. These folds strike nearly north and plunge steeply northward on the north flank of Mount Glen, though their tectonic axes become nearly horizontal at the quadrangle boundary. In many places these folds have sheared-out limbs or show more or less severance of the Cretaceous cover from the underlying Paleozoic rocks. Apparently the only thrust outlier in this part of the range is a single small mass of Epitaph dolomite resting on the Earp formation about half a mile east and a few hundred feet south of the common north corner of the Pearce and Benson quadrangles.

The structure of the western flank of the range is far more broken, and a satisfactory synthesis of the observations has not been possible. The plexus of faults in lower Jordan Canyon and just west of Dragoon Peak seems reasonably interpreted as due to shearing out of fold limbs during a late stage of the tight folding represented farther east. The most easterly of the faults shown in plate 6, section I–I', seems indeed to have been formed in pre-Cretaceous time, and to have been little, if at all rejuvenated during the post-Cretaceous orogeny. (See p. 124.) Farther south, near the head of Jordan Canyon, the abrupt changes in attitude of the highly altered Bisbee formation seem to require explanation by faulting. One fault drawn on this basis (the scale of pl. 5 prevents showing more than a small fraction of the attitude readings on which it is based) trends northeastward from the tip of the Horquilla outcrop 1½ miles east of the Fourr Ranch. This fault seems to have a steep dip. It was followed for only a few hundred feet northward from the Jordan Canyon divide but could not be mapped farther northeast because of approximate structural conformity of the two sides and absence of "marker" beds. A fault of apparently low dip crops out just east of this high-angle fault, which seems to have cut it off, and can be traced by the marked discordance in strike of its wall rocks nearly along the 5,800-foot contour at the head of Jordan Canyon. It seems to cut off a northward-trending fault on the east wall of Jordan Canyon and, with a steepening westerly dip, brings Cretaceous rocks over the Earp and Horquilla formations on the eastern side of this fault. Thence it can be traced south with Cretaceous rocks in both walls and appears to join a fault along the Bisbee-Horquilla contact where that fault crosses the northwestern spur from Mount Glen. Neither fault was recognized for more than about half a mile west of this junction. It seems likely that more detailed mapping might permit determining the further extent and mutual relations of these faults; the present information does not justify any well-supported hypothesis relating this fault to the general structure of the range.

The structure of the mountain between Jordan Canyon and Fourr Ranch is dominated by a nearly vertical northward-trending breccia zone ranging from about 200 feet to 1,000 feet in width and separating Pinal schist to the east from the Bisbee formation This breccia contains a mappable body of Horquilla limestone at its north end, where it is cut off by the Stronghold granite at the base of the mountain. Farther south it is chiefly composed of brecciated granite gneiss, but fragments of granite gneiss occur with the limestone at the north end and fragments of Paleozoic and Cretaceous sedimentary rocks with the dominantly granitic gneiss breccia toward the south. On the east side near the north end of this breccia, a body of Horquilla limestone appears, seemingly intercalated between a high-angle fault on the north and a low-angle southward-dipping fault over which Pinal schist comes in on the south. The limestone wedges out to the southeast and cannot be satisfactorily related to the neighboring tectonic blocks. I have interpreted the south fault as a thrust (section I–I'), but the scale of mapping and absence of marker beds in the Pinal to the southeast prevent tracing the postulated thrust as far as the northeastward-trending fault described in the preceding paragraph, as should be possible if the interpretation implied in section I–I' is to be established.

The south end of the vertical band of granitic gneiss breccia described is cut off by a well-exposed fault with a fairly steep northerly dip that brings Horquilla limestone beneath the breccia band and the adjacent blocks of Bisbee and Pinal rocks to either side. This eastward-trending fault seems clearly younger than the breccia zone. This age relation makes difficult a correlation of the breccia to the north with the body of granitic gneiss exposed on both walls of Fourr Canyon about a quarter of a mile farther west, for the fault that bounds this western body of gneiss on the east definitely cuts off both the Horquilla limestone and the fault bounding it on the north. A more detailed mapping of the Bisbee rocks than was possible on the scale of plate 5 would be needed to clarify this somewhat chaotic structure.

MOUNT GLEN FAULT

A fault, here called the Mount Glen fault, is the structural feature most widely traceable in this segment of the range (pl. 13). On the eastern foothills, about three quarters of a mile northwest of the mouth of Stronghold Canyon, this fault emerges from the alluvium with a fairly steep northwesterly dip. A wedge of Escabrosa limestone locally lies with faulted contacts between a thin slice of Horquilla limestone in the hanging wall and Abrigo limestone in the footwall.

A steeply dipping reverse fault seen on the low saddle a mile farther northwest, in sec. 11, T. 17 S., R. 23 E., brings Colina limestone and Epitaph dolomite over the Bisbee. This may be a warped branch of the Mount Glen fault as suggested in plate 6, section *II–II′*, but this fault is also possibly younger than the Mount Glen because it is about parallel to faults farther south that are known to be younger than the thrusts. This possibility is suggested by the queried fault shown on the section and by the symbol indicating a buried fault on the map of plate 5.

The branches of the Mount Glen fault join about three quarters of a mile to the west of the mountain front, near the eastern part of sec. 14, T. 17 S, R. 23 E. Here the fault brings much sheared Horquilla limestone over Escabrosa. This stratigraphic succession is of course the normal one, but the shearing out and transection of beds in both formations enable the fault to be readily traced. Halfway up the eastern slope of Mount Glen the fault is offset about a thousand feet by a nearly vertical northward-trending fault that is clearly older than the Stronghold granite. West of this offset, the Mount Glen fault is warped and cuts the upper Horquilla strata nearly normal to bedding, finally bringing the Earp formation over the Escabrosa. It trends south on the upper slope of Mount Glen and is cut off abruptly by the Stronghold granite. What is interpreted as the same fault emerges from the granite contact on the south face of Mount Glen with a steep easterly dip. It trends northward for about 1,500 feet and then flattens about 500 feet below the mountain crest, outlining two sides of an inlier of Escabrosa limestone beneath the Earp. The inlier is bounded on the west by a nearly vertical fault that extends southward to the granite contact. This younger fault probably has a maximum displacement of only about 200 feet and may be pivotal, with the displacement at the north being relatively downward on the east while that at the south is probably downward on the west. Slight warping of the Mount Glen fault could readily account for the apparent pivotal movement, however.

The Mount Glen fault again appears north of the granite contact about a quarter of a mile farther west, where, for a few feet, it separates Martin limestone on the west from the Earp formation on the east. It cuts the beds in the lower block at a high angle and then has the usual relation, with Escabrosa limestone in the footwall. It passes up the western spur at a dip about parallel with the surface but flattens below the crest of the western ridge of Mount Glen and outlines a hook-shaped part of the overriding block which lies parallel to the ridge. The younger fault referred to in the preceding paragraph cuts the Mount Glen fault about 1,000 feet west of the summit of the mountain. The trace of the Mount Glen fault west of this offset turns abruptly westward and must indicate a sharp reversal in the curvature of the fault. (See pl. 6, sec. *II–II′*.)

A few hundred feet to the west, the Mount Glen fault splits. The upper branch can readily be traced across the western spur of Mount Glen, where it brings the Earp formation over a thin wedge of Horquilla limestone; but from a point about 1,000 feet down the northern slope, where Horquilla limestone appears in the overriding block, its trace is difficult to follow farther, owing both to heavy brush and the similarity of beds above and below. Its probable course, as indicated on the map, is such as to join the next lower branch in the narrow gulch at the head of Fourr Canyon.

The lower branch of the Mount Glen fault separates the Escabrosa limestone in the footwall from the thin wedge of Horquilla limestone beneath the upper branch. At about the quadrangle boundary this fault also splits, the upper branch curving sharply northeastward, then north and northwest, while the lower branch curves sharply southward. The narrow gulch at the head of Fourr Canyon has cut through the upper of these thrust plates and exposes beneath it a strip of Escabrosa limestone in a wedge about 1,500 feet long and only a few scores of feet wide. The Mount Glen fault here dips westward, and to the south it can be traced readily for more than a mile until it is again cut off by the Stronghold granite in the north wall of Stronghold Canyon. Along this segment the Horquilla limestone rests on the Escabrosa except at the extreme south end, where the fault cuts across the Escabrosa and brings the underlying Martin limestone into contact with the Horquilla.

The lowest branch of the Mount Glen fault observable here splits away at the quadrangle boundary from the branch just described. It cuts folds in both the overlying and underlying blocks. At the south, however, where a wedge of Martin limestone occurs, the Escabrosa limestone is the only formation exposed in the hanging wall. The footwall block exposes the Martin and Escabrosa limestones.

A fault that is interpreted on plate 6, section *III–III′*, as a part of the Mount Glen fault is exposed about a mile south-southeast of the Fourr Ranch, on the northeastern side of the first considerable canyon south of Fourr Canyon. Where this fault emerges from the alluvium, it has Escabrosa limestone below and Horquilla limestone above, trends nearly eastward, and dips northward at about 40°. Less than a thousand feet east of the alluvium, the fault transects a steeply eastward-dipping prethrust fault in the footwall block; and thence, for half a mile to the southeast, it brings the Horquilla limestone of the hanging wall against Abrigo limestone in the footwall. The fault along this segment dips northeastward at about 30°. It and the underlying block of Cambrian rocks are cut off on the south by the Stronghold Divide fault—a normal fault of generally easterly trend but curving trace, with a dip of about 50° S.

What is believed to be the displaced segment of the Mount Glen fault appears in the hanging wall of the Stronghold Divide fault about 2,000 feet southwest of its footwall intersection. Here the Bolsa quartzite, believed to belong to the same structural block as the footwall block just described, appears beneath the Escabrosa limestone just north of the contact of the Stronghold granite. The fault is cut off by the granite contact about 800 feet to the southeast, but a fault of arcuate trace exposed in the next easterly tributary of Stronghold Canyon, Benson quadrangle, is believed to represent still another segment of the Mount Glen fault. This segment, where cut off by the Stronghold granite, has Horquilla limestone in the hanging wall and Pinal schist below. The footwall block is faulted, as in the area to the northwest, and Bolsa quartzite is absent, but the highly folded Abrigo and Martin limestones appear in it to the north. Two slivers of Escabrosa limestone intervene locally between these formations and the overriding Horquilla limestone. The arcuate trace of the fault cuts the bedding of both overlying and underlying blocks before being cut off to the east by the Stronghold granite. The interpretation of these relations as indicating a quasi-window in the Mount Glen fault implies no more warping of that fault than is demonstrable by continuous tracing on Mount Glen.

The alluvium along the western foot of the Dragoon Mountains between Fourr and Stronghold Canyons prevents tracing the farther extent of the Mount Glen fault. As shown on plate 6, section *III–III′*, a normal fault apparently cuts off the footwall block of earlier Paleozoic and pre-Cambrian rocks. At least three thin thrust sheets appear on the low hill about a mile south of the Fourr Ranch; it is impossible, however, to determine their relation to the Mount Glen thrust though it seems probable that they are all tectonically higher, the interpretation indicated on the section.

STRONGHOLD DIVIDE FAULT

The fault here called the Stronghold Divide fault is exposed along the south side of the divide between Stronghold Canyon, Benson quadrangle, and Fourr Canyon. (See pl. 13.) This fault dips southward at 35° to 60° and accordingly has a very tortuous trace because of the general southerly slope and irregular topography. Judging from the offset of the base of the Bisbee formation, the fault is normal, and its throw is about 400 feet on the spur about 4,500 feet west of the 7,001-foot hill on the divide. The Bisbee formation here is folded, however, so that the actual displacement may be considerably more than this. The offset of the Mount Glen fault would suggest a much larger throw, but the known warping of this thrust surface again prevents accurate measurement.

On the 7,001-foot peak, half a mile west of the quadrangle boundary, the measurable displacement of the fault is much greater, for it brings the Bisbee formation in the hanging wall against Horquilla limestone in the footwall. The Bisbee formation is in an overturned syncline, whose axial plane dips southwest at about 50°. Small patches of Colina limestone overlie the Bisbee on the overturned limb of this fold, and on the upright limb the Bisbee formation, Colina limestone, and Earp formation all appear in normal succession. A minimum estimate of the throw of the Stronghold divide fault here is about 2,000 feet. The rocks of the hanging wall block are much more intensely folded and sheared than those of the footwall. It seems likely that the downthrow of the hanging wall of this fault has preserved the higher parts of the Mount Glen thrust sheet which have been eroded from the footwall and that the more intense contortion of these higher parts indicates a still higher overriding block. The successive thrust sheets to the west and those south of the Stronghold granite suggest that such thrust masses were widespread. East of the 7,001-foot hill, the Stronghold Divide fault separates Earp and Horquilla rocks in the footwall from the Horquilla limestone of the hanging wall.

Both to the east and west, the fault is cut off by the Stronghold granite. Beyond the fact that it is obviously younger than the Mount Glen fault and older than the intrusion of the Stronghold granite, its place in the tectonic development is unknown. No comparable faults of this trend and age have been elsewhere recognized.

CHOCHISE STRONGHOLD AREA

The Stronghold granite makes up most of the range south of the north walls of the two Stronghold Canyons as far as a northeasterly line through Cochise Peak. Time did not permit attention to any internal structures the granite may possess; if any flowage structures exist they are not obvious. No faults were recognized in this part of the range, and the granite is clearly younger than all of the folding and thrusting of the area.

Despite the local disregard of pregranitic structural features by the granite contact, there is a strong suggestion of a gentle doming of the rocks over this part of the range. If the Mount Glen thrust is considered as a datum, it stands higher on Mount Glen, at the axis of the exposed granite area, than either to the east or west. Furthermore, though there are local reversals and the Stronghold Divide fault may be a contradictory phenomenon, the main structural culmination must have been near Cochise Stronghold. The northerly plunge of the Mount Glen fault has already been described. The block of Pinal schist, Cochise Peak quartz monzonite, and lower Paleozoic rocks which forms the eastern foothill between Cochise Ranger Station and the mouth of Grapevine Canyon seems reasonably to be correlated with the overriden block of the Mount Glen fault. If this correlation is justified the scattered outcrops of Cambrian and pre-Cambrian rocks to the south and west, beneath the southward-plunging thrusts east of Cochise Peak, furnish strong evidence of tectonic closure about three sides of the granitic mass. As pointed out in the following section, the southerly axial plunge seems to persist for several miles, at least in the lower tectonic blocks.

It should be emphasized, however, that the doming indicated by the relations just summarized by no means adequately accounts for all of the space now occupied by the intrusion. There is not the slightest suggestion of "shouldering" action of the intrusion at any of its local contacts, but there are innumerable evidences of its permissive, rather than forceful, emplacement. The intrusive contacts cut all the older local structures without regard to their attitude in detail, and on the west side of the range, in particular, they transgress in-dipping blocks as indifferently as out-dipping. The exposures of Stronghold granite for several miles to the north along the west side of the range show comparable indifference to older structures at this (higher) tectonic level also. (See pl. 6, sec. *I–I′*.) The situation may be epitomized by pointing out that the structural relief of the country rock considered in the large may be about 1,000 feet in the transverse profile of the range, whereas the intrusion shows a present relief of about twice this amount and shows no country rock along the western base of the range where it must clearly cut higher tectonic levels than on the axis. In absence of exposures to the east and west, no precise figures are possible, but it seems clear that the doming can account for much less than half—perhaps a trivial part—of the inferred volume of granite.

AREA BETWEEN STRONGHOLD GRANITE MASSIF AND MIDDLE PASS

(Pl. 2, secs. *IV–IV′*, *V–V′*, and *VI–VI′*)

GENERAL FEATURES

The metamorphic aureole about the Stronghold granite mass includes most of the area north of Middle Pass, so that the lithologic distinctions between the several formations have been blurred, as in the area to the north of Cochise Stronghold. The innumerable faults, the shearing out of many of the formations, and the contact metamorphism combine to obscure many of the details and perhaps some major features of the structure.

So far as it has been elucidated, the structure of this part of the range is dominated by low-angle thrust faults, with very few folds comparable to those north of Cochise Stronghold. In the following sections these structures are described, beginning with what is apparently the lowest tectonic level exposed, that in the northeastern part of this segment of the range.

It seems reasonable to consider the interrupted homocline of rocks of early Paleozoic age overlying Pinal schist and Cochise Peak quartz monzonite southeast of the Stronghold Ranger Station as forming a continuation of the block immediately below the Mount Glen fault on the northwest side of Cochise Stronghold. The later intrusion of the Stronghold granite has disturbed the rocks of this homocline, and alluvial deposits have masked parts of it, but the scattered exposures of Pinal schist and Bolsa quartzite between the mouth of Grapevine Canyon and the northwestern quarter of sec. 4, T. 18 S., R. 24 E., are considered to be parts of this lowest of the exposed tectonic units.

If the continuity of this structural unit, prior to the intrusion by the Stronghold, be conceded, it is significant that both to the north and south it is overlain by a low-angle fault, above which the structural complexities are far greater than within this lowest unit. Accordingly this lowest of the exposed structural units is also assumed the lowest unit involved in the thrusting and is probably autochthonous. On this interpretation the Mount Glen thrust is to be correlated with the one exposed at the eastern foot of the range in sec. 5 (unsurveyed), T. 18 S., R. 24 E. The Mount Glen fault and this basal one to the south resemble the so-called strip thrusts or decollement structures of the Alpine geologists, whereas the higher faults both north and south of the granite are not so closely related to bedding movements.

POSTULATED CONTINUATION OF MOUNT GLEN THRUST

Scattered exposures of Cambrian rocks are found for a distance of more than 2 miles from a point just south of the mouth of an unnamed canyon, which is just about a mile south of Grapevine Canyon. These exposures are regarded as equivalent in tectonic position to the rocks beneath the Mount Glen thrust north of Cochise Stronghold. (See pl. 13.) Alluvium and the invasion of the Stronghold granite have concealed or destroyed the contacts of these Cambrian blocks with overlying rocks except in two localities: one on a spur south of the canyon and about 1½ miles above its mouth and another on the crest of a ridge about a mile farther west. At the first locality, the Bolsa quartzite and Abrigo limestone are overlain by highly sheared limestone—undoubtedly of late Paleozoic age but no longer recognizable as to more precise stratigraphic position. The thrust between the Cambrian and these higher rocks is well exposed, strikes east-northeast, and dips southward at a moderate angle. This is regarded as the continuation of the Mount Glen thrust.

At the second locality, a mile farther west, the Bolsa quartzite is exposed beneath a southwest-dipping thrust that carries Bisbee formation over it. The nearly continuous sheet of sheared out limestone above this sliver of Bisbee formation is probably part of the one that overlies the Cambrian rocks at the first locality mentioned. For this reason the Bisbee sliver is regarded as probably a horse in the Mount Glen fault zone although this fault where it is certainly identifiable to the north does not come in contact with Cretaceous rocks.

The areal distribution of the Cambrian rocks in this unnamed canyon suggests a general southerly dip of the Mount Glen fault above them, with a probable eastward component near the canyon mouth. These relations are expressed on the map of plate 5 and on plate 6, sections *V–V′* and *VI–VI′*.

HIGHER THRUST SHEETS IN FOOTHILLS EAST OF MIDDLEMARCH CANYON

The highly sheared limestone of late Paleozoic age, mentioned in the preceding section as overlying the Cambrian rocks, forms a nearly continuous outcrop about 1,500 feet wide that extends from the alluvium at the foot of the range for about 1½ miles to the west. The crude foliation in this belt dips generally southward at angles of 20° to 35°. It is limited on the south by a thrust of similar attitude, with Cretaceous rocks above it. At least part of these Cretaceous strata are probably from low in the Bisbee formation, as sheared limestone conglomerate is abundant. Their attitude and that of the associated sandstone and shale beds is far from regular, however, and possibly a considerable stratigraphic range of the Bisbee is represented in this block. The dip, though irregular, is generally southward at angles of 40° or more.

Within this block of Bisbee formation, in the western part of sec. 8 (unsurveyed), T. 18 S., R. 24 E., is a wedge of sheared limestone, probably part of the Colina limestone. This wedge, only 200–300 feet wide, can be traced for about 600 feet and is interpreted as a dragged block on a minor thrust.

This block of Bisbee formation in the foothills north of Middlemarch Canyon is probably a part, structurally, of the great synclinal prism exposed to the southeast, though some relatively minor faults may intervene.

STRUCTURE IMMEDIATELY EAST OF MIDDLEMARCH CANYON

All of the structural features of the foothills just described are cut off by a high-angle fault trending northwest from near the center of the north line of sec. 17 (unsurveyed), T. 18 S., R. 24 E. This fault can be traced for nearly a mile by the offset of the stratified rocks along it. There is a suggestion, owing to the apparent jog in the contact of the Stronghold granite, that the fault is postintrusion, and its straight course across the topography indicates a steep dip. For these reasons, admittedly not conclusive, it is provisonally regarded as a postintrusion fault and is drawn, on plate 6, sections *V–V′* and *VI–VI′*, as essentially vertical with downthrow on the east. Nevertheless, the fault is possibly older than the Stronghold granite and representative of a broken involution, in which a new steeper thrust has arisen beneath the older and cut off the older, as has clearly happened in the case of the main Dragoon thrust. If this is another example of such a steep upthrust beneath older flatter thrusts, it most likely should be drawn as concave to the west and not as cutting the Stronghold granite as has been done on plate 5 and plate 6, sections *V–V′* and *VI–VI′*. The throw of the fault is about 1,500 feet judging by the offsets of the several thrust sheets.

The tectonic units to the southwest of this fault may plausibly be correlated with those to the northeast, though the parallelism of the sequences is not complete. The lowest exposed sheet immediately to the west of the fault is a breccia containing blocks of schist, limestone, dolomite, and quartzite. The individual blocks composing it are too small to be portrayed on the scale of plate 5, on which this sheet is shown as "thrust breccia." Indeed, the body mapped as Bisbee formation at the northwest end of this belt contains many small blocks of rocks of Paleozoic age and of Cochise Peak quartz monzonite and might perhaps better have been included under the breccia symbol, although it is dominantly composed of Bisbee formation. This breccia sheet, though interrupted by a projection of granite from the Stronghold mass, appears on strike across the granite, forming the plate previously described as overlying the Mount Glen thrust and resting on the Bolsa quartzite. Accordingly, this entire breccia sheet is regarded as marking the Mount Glen thrust in this area.

Overlying the breccia sheet is a highly sheared mass of limestone, almost certainly of late Paleozoic rocks. This is correlated with the similar sheet overlying the Cambrian to the north and northeast. Southeastward it can be traced to a wedge before reaching the high-angle fault separating these blocks from those in the foothills to the northeast. More than 3,000 feet of offset on the high-angle fault, however, render this wedging out immaterial to the question of correlation of the thrust sheets. Toward the northwest, this sheared-out limestone block is also interrupted by an apophysis of Stronghold granite about 1,200 feet wide, but a similar mass on strike beyond this can be followed for nearly a mile to the northern spur of Cochise Peak before being finally cut off by the main mass of Stronghold granite.

Resting on this sheared limestone plate is a mass of Bisbee formation. East of Middlemarch Canyon, the outcrop width of this plate is more than 1,500 feet. Here it is essentially on a dip slope, and the outcrop of the fault is highly irregular owing to dissection by tributary streams. The plate is not more than a few score feet thick, as can be seen by following it southeastward. It narrows in outcrop width to only 200 feet where it is cut off by the high-angle northwest fault. Northwestward, across the apophysis of Stronghold granite east of Cochise Peak, a similar lithologic unit lies in proper tectonic relation above the sheared limestone thrust plate. It wedges out northward into a breccia dominantly composed of blocks of Paleozoic rock and those of the Cochise Peak quartz monzonite, north of Cochise Peak.

This Bisbee sheet seems possibly to be correlated with the part of the Bisbee block to the east that lies below the wedge of Colina limestone. The Bisbee sheet in Middlemarch Canyon is also locally overlain by a sheet of Naco rocks. Northeast of Cochise Peak this overlying sheet is chiefly composed of the Colina limestone, with some mixture of blocks of Cochise Peak quartz monzonite, though immediately west of the high-angle northwest fault, it is chiefly of Earp formation. When account is taken of the fault offset, this variance in stratigraphic position of the components seems no bar to correlation of the sheets.

Resting on the slice of Earp formation is a fault block composed of Pinal schist and Cambrian and Devonian rocks. In places this sheet seems to have cut through the sheet of middle Naco rocks and rests directly on the lower block of Bisbee formation. Sporadic outcrops—much faulted and obscure—permit following this sheet up the valley of Middlemarch Creek into the southeastern spur of Cochise Peak. The "fault breccia" shown here on plate 5, between slices of Bisbee formation, is composed of a confused jumble, chiefly of early Paleozoic rocks.

Probably the Cretaceous strip to the east of the terminal wedge of this breccia sheet at the base of Cochise Peak can be correlated structurally with the limestone conglomerate cropping out on the spur north of the mouth of Middlemarch Canyon; both rest on upper Naco rocks. On this spur the limestone conglomerate, surely a lower part of the Bisbee formation, is faulted against the Bolsa quartzite to the west with a high-angle boundary. As the fault does not cut the thrust that overlies the Earp slice to the north, it may be only an internal break in a larger tectonic block. Exposures do not permit a fruitful discussion of this question.

The highest tectonic unit recognized east of Middlemarch Canyon is a small body of limestone conglomerate of the Bisbee formation that lies on the Pinal schist at the east side of the canyon mouth. This body is probably a part of the block of Bisbee formation exposed on the west side of the canyon. The fault beneath this Bisbee mass is exposed on strike to the north-northwest, where it brings the Bisbee over the breccia of early Paleozoic rocks described. The fault dips about 40° SW., judging from its trace on the topography and local exposures.

STRUCTURE BETWEEN MIDDLEMARCH CANYON AND SOREN'S CAMP

Soren's Camp (unnamed on pl. 5) lies in the canyon about half a mile due south of Cochise Peak. The structure to the northeast of Soren's Camp is shown on plate 6, section IV–IV′, and represents the northwestern continuation of the thrust plates found to the southeast near and to the east of Middlemarch Canyon, described in the preceding section.

The most continuous tectonic block in this area is that lying in and immediately east of Soren's Camp and extending south-southeast from Cochise Peak to Middle Pass. At the north it is composed entirely of Cochise Peak quartz monzonite. The underlying thrust plane is well exposed on the northeastern slopes of Cochise Peak where it dips beneath the peak at about 35°. The block rests on much-sheared Colina limestone, with local breccia fragments of early Paleozoic rock; and this, in turn, rests on a lower block of Cochise Peak quartz monzonite. A still lower thrust plate of limestone of late Paleozoic age is present in places, though it and some of the higher slices have elsewhere been destroyed by the Stronghold granite massif. The southeastern continuations of these lower thrust masses have been described in the preceding section. The two principal blocks not there described are the uppermost of these plates.

Due east of Soren's Camp the thrust at the base of the Cochise Peak quartz monzonite is exposed with a somewhat steeper dip than to the northwest—about 55°. Here the quartz monzonite rests on a thrust breccia dominantly composed of Bisbee formation. At the Cobra Loma prospect in the gulch half a mile south-southeast of Cochise Peak, the fault dips 65°, with the Cochise Peak quartz monzonite resting against black slate, lithologically so different from all other rocks in the area as to invite the question as to the possibility of its Late Cretaceous age, though it is mapped on plate 5 as Bisbee formation. The intervening fault can readily be traced to the southeast, with an apparently steepening dip until the fault boundary is essentially vertical, about a mile southeast of Soren's Camp, on the ridge west of Middlemarch Canyon. The block of Cochise Peak quartz monzonite here has a cap of Bolsa quartzite sporadically preserved. Excellent exposures show this contact to be intrusive.

Two puzzling outcrops are found on the eastern slope of the ridge in the SE. cor., sec. 12, T. 18 S., R. 23 E. (unsurveyed). One is a cap of Bolsa quartzite about 40 feet thick, resting on westward-dipping limestone conglomerate to the east of the high-angle fault. A few hundred feet to the south above the old Middlemarch mine (not shown on pl. 5), a hill crest is capped with massive limestone resembling (and mapped as) Escabrosa limestone, which rests with an almost horizontal contact on a plate of Bolsa quartzite. The quartzite in turn lies with fault contact on conglomeratic Bisbee rocks. Both limestone and quartzite are cut off to the west by a nearly vertical fault, so that a wedge of conglomerate of Cretaceous age separates them from the Cochise Peak quartz monzonite and its eastern boundary fault. These thrust slivers cannot be correlated specifically with any of the larger units but probably belong to either the immediately overlying or underlying sheet as the high-angle fault cutting them off cannot extend much farther north and hence probably has a relatively small displacement.

The high-angle fault bounding the Cochise Peak quartz monzonite and its Bolsa quartzite cap on the east can be readily traced for another thousand feet to the south. On the north wall of the eastward-trending course of Soren's Canyon, just west of its junction with Middlemarch Canyon, in the NE¼, sec. 13 (unsurveyed), T. 18 S., R. 23 E., conglomerate of the Bisbee overlaps onto the quartz monzonite in what appears to be a depositional contact, though all the rocks here are highly disturbed and altered to hornfels. It has accordingly seemed best to postulate that the steepening of dip of the thrust fault southeastward from Cochise Peak is not alone responsible for the straight boundary but that a younger vertical fault is responsible and has dropped the block to the west relative to the Bisbee area on the east. (See pl. 6, sec. *VI–VI′*.) Similar relations are found on strike to the south near Dragoon Camp.

The west boundary of the block of Cochise Peak quartz monzonite, in Soren's Canyon, is definitely a fault, along which the comminution of the intrusion locally gives the false impression of a chilled border. Thin sections show the finer grain to be due to microbrecciation and incipient mylonitization. Several prospect pits show the fault to dip westward at about 60°–70°. It can be followed southward to the canyon below Middle Pass, with the Bisbee formation in the hanging wall. On the ridge east of Middle Pass an intrusive contact of Cochise Peak quartz monzonite with Bolsa quartzite and Abrigo limestone is excellently exposed. The exposed block of Cochise Peak quartz monzonite and its host rock is cut off to the southeast by a fault that drops Bisbee against it. This fault cannot be followed beyond the canyon bottoms, either to the northeast or to the southwest. The southward continuations of these structures are discussed in connection with the structures between Middle Pass and South Pass.

STRUCTURE NORTH OF SOREN'S CAMP

The fault block of Cochise Peak quartz monzonite extends northward from Soren's Camp. About 2,000 feet north of the cabins, the intrusive rock invades a spotted schist, with no possibility of the contact being faulted. This schist mass continues northward for more than 2 miles as a roof pendant in the Stronghold granite massif. On plate 5 this schist is shown as Pinal. It should be emphasized, however, that this stratigraphic assignment is questionable and more detailed investigation may well reveal that the mass is composed of the Bisbee formation. This is one of the most crucial of the structural uncertainties resulting from the intense metamorphism connected with the intrusion of the Stronghold granite. Whatever the true stratigraphic position of this mass of spotted schist, its relations to the Cochise Peak quartz monzonite differ radically from those of the unquestioned Bisbee on the south side of China Peak. The northerly schist mass is clearly invaded by the Cochise Peak quartz monzonite; the southerly Bisbee mass is as definitely overthrust on the same body. Accordingly, there can be no doubt that this body of schist forms an integral part of the Cochise Peak block.

The next lower thrust block, of Colina limestone, wedges out north of Cochise Peak. A disturbed zone in the schist (shown in part on plate 5) may mark the fault for another half a mile, but this is uncertain; and in any event, the exposures do not suffice to trace it further north. Tongues extending southwestward from the Stronghold granite massif interrupt the continuity of the structurally lower thrust plates found to the southeast. There is, however, no question that the schist rests in fault contact on the body of Abrigo limestone altered to hornfels and thrust breccia (now highly serpentinized, and charged with garnet, epidote, and hedenbergite) about a mile north-northwest of Cochise Peak. The fault, as exposed in prospecting pits, dips westward 20°–25°. The metamorphism by the Stronghold granite was later than the faulting.

For about a mile from its northern tip, the western boundary of the schist mass is the intrusive contact of the Stronghold granite. For the next half mile to the south, a body of marble regarded as probably representing Escabrosa limestone borders it on the west. The contact is a fault with a horse of Bolsa quartzite in the fault zone. Although the bedding in the marble appears to lie at gentle dips, the contacts are steep. A small body of quartzite, interpreted as Bolsa, also occurs on the western side of the marble, between it and the Stronghold granite.

One of the most complex areas is on and near China Peak (pl. 6, secs. *IV–IV′* and *V–V′*). Detailed description is impossible within reasonable compass. Broadly, however, on and north of China Peak there seems to be a series of thin fault blocks, chiefly of early Paleozoic age and Pinal schist, thrust over the Pinal schist at relatively low angles. Some high-angle faults cut the thrusts also. South of China Peak these thrusts override Cretaceous rocks, and owing to subsequent contact metamorphism, it is uncertain locally how much of the apparently conglomeratic rock present is tectonic breccia and how much is altered limestone conglomerate.

Despite the intense shearing shown by all these rocks, it is impossible to trace any of the thrust sheets for more than about 2,000 feet on strike into the Bisbee block that extends from Soren's Camp to Middle Pass. For this reason and because the Bisbee can be seen in excellently exposed depositional contact on the Escabrosa and Horquilla limestones along the west side of this block to the south, these thrusts in the China Peak area are regarded as very minor features. They probably resulted largely from stripping movements of the sedimentary rocks from the Pinal, partly localized by the pre-Bisbee unconformity.

STRUCTURE WEST OF MIDDLE PASS

(Pl. 6, secs. *VI-VI′*, *VII-VII′*, *VIII-VIII′*)

In the foothills near Sala's Ranch, about 2 miles due west of the divide at Middle Pass, Cambrian and Devonian rocks are invaded by the Stronghold granite. The rocks of early Paleozoic age are cut by several faults and by apophyses of the granite, but form in general a relatively simple southeastward-dipping homocline. This seems to be essentially the same block as the one described in the preceding section as containing the locally severed Bisbee formation south of China Peak. The westward-dipping reverse fault extending southeastward from the granite contact at the 6,100-foot contour, which is the only break in the continuity of the two blocks, has a throw of only about 150 feet.

The reverse fault mentioned increases in throw toward the southeast. About half a mile from the granite contact it is joined by a branch from the southwest. Southeast of the junction the throw, measured by the offset of the base of the Horquilla limestone, amounts to at least 1,000 feet. The unconformably overlying Bisbee formation and the Horquilla limestone, which comes in on the eastern block toward the south below the Bisbee, are both absent from the hanging wall. This fault then, though much less striking in stratigraphic offset, is the only one north of Middle Pass at all comparable structurally to the main Dragoon fault south of that canyon. It is interpreted as the northern segment of the Dragoon fault, along which the displacement diminishes rapidly toward the north.

The block to the northeast, between this fault and the block of Cochise Peak quartz monzonite, contains at least two anticlines with an intervening syncline in the Cretaceous cover. These are interpreted as due to fault drag because they are more tightly compressed toward the southeast.

The hanging wall block, in this segment of the Dragoon fault, is chiefly composed of Escabrosa limestone with locally a little Horquilla limestone. In the canyon walls in the NE¼ sec. 24 (unsurveyed), T.18 S., R. 23 E., an anticline brings in the Martin limestone beneath the Escabrosa. This anticline is, however, cut by low-angle faults as shown by drag blocks of Cambrian rocks between the Escabrosa and the Martin and within the Martin, as well as by the duplication of part of the Martin over a wedge of Escabrosa on the south wall of the canyon.

Minor faults repeat the Martin and Escabrosa blocks north of the canyon mouth, as shown in plate 6, section *VI–VI′*.

STRUCTURE BETWEEN MIDDLE PASS AND SOUTH PASS

(Pl. 6, secs. *VII-VII'*, *VIII-VIII'*, *IX-IX'*, *X-X'*, *XI-XI'*, and *XII-XII'*.)

THE DRAGOON FAULT

The most conspicuous structural feature of the segment of the Dragoon Mountains here considered is the Dragoon fault. This is a high-angle reverse fault whose displacement seems to increase markedly toward the south. It is clearly seen on plate 5 as marking the eastern boundary of the block of intrusive rocks and rocks of Paleozoic age that constitutes the main divide of the mountains, separating it from the large area of Bisbee formation in the eastern foothills.

The northerly extension of the Dragoon fault has been described in the preceding section. On the south side of the canyon below Middle Pass the fault is well marked, with Horquilla limestone in the hanging wall and Bisbee formation in the footwall. A few prospect pits indicate that the fault dips westward about 70°. The Horquilla limestone in the hanging wall strikes almost normal to the fault trend and dips southward about 35°; the strike of the Bisbee is nearly parallel to the fault, and the dip is steeply overturned to the west.

Half a mile south of the canyon, the Dragoon fault is offset by a steep easterly fault, the only break in its continuity for several miles. South of this transverse fault, the Horquilla limestone of the hanging wall wedges out between the fault and a higher thrust plate of Escabrosa limestone. This body of Escabrosa is a fault outlier forming the summit of Black Diamond Peak and overlying the steeply dipping Escabrosa and Horquilla of the lower slopes at a gentle angle.

At the southern boundary, which may be a minor fault restricted to the hanging wall block of this Escabrosa plate, Horquilla limestone again forms the hanging wall of the Dragoon fault. This mass is not, however, continuous with the one in similar relation to the north, for it rests with a steep eastward-dipping fault contact on Earp and Horquilla strata to the west. It is the most northerly of several similar eastward-dipping thrust sheets described in subsequent sections.

A short distance west of Dragoon Camp a still higher eastward-dipping thrust sheet, of Colina limestone, overlies the Horquilla limestone and forms the hanging wall of the Dragoon fault. The Dragoon fault here dips westward about 60°; the hanging wall thrusts dip steeply eastward, and the bedding of the associated limestones is highly irregular both in strike and dip. The Bisbee formation of the footwall of the Dragoon fault is chiefly limestone conglomerate for long distances parallel to the fault and locally dips away from it at angles as low as 25°. Most dips are much steeper, however; and in many places the beds are overturned.

Colina limestone forms the hanging wall for about 1½ miles, then wedges out and gives place to the underlying plate of Earp formation which dips eastward about 35°. There is a fairly abrupt swerve in the course of the Dragoon fault in the northeast corner of sec. 31, T. 18 S., R. 24 E. In this salient, a sheet of Colina limestone reappears—probably part of the one that had wedged out half a mile to the northwest. It is overlain by a fault outlier of Bolsa quartzite, belonging to a still higher tectonic level.

South of the salient just mentioned, the Dragoon fault appears to be offset in several places by small northward-trending faults. Lower stratigraphic levels abut the fault toward the south, with first the Earp, then the Horquilla, and finally the Escabrosa being transected. In sec. 3, T. 19 S., R. 24 E., the Martin limestone occurs in the hanging wall. Here the fault dips 50° W., the Martin about 40° E., and the Bisbee formation in the footwall about 70° E. Farther south the Copper Belle monzonite porphyry forms the hanging wall. About a mile northwest of South Pass an obscure fault in the footwall of the Dragoon fault cuts off the Bisbee formation, and from this point to South Pass the footwall is composed of andesite tentatively regarded as of pre-Bisbee age. (See p. 68.) The thrust slice of monzonite porphyry in the hanging wall also disappears about half a mile north of South Pass, so that the rocks of early Paleozoic age—Martin limestone, Abrigo, and Bolsa—appear in succession to the south. A minor fault separates these rocks from the Pinal schist to the west. The Dragoon fault in South Pass dips about 45°–50° SW.

STRUCTURE WITHIN THE DRAGOON THRUST BLOCK

Considered in the large, the lowest exposed structural block west of the Dragoon fault is anticlinal. As mentioned on (p. 142), at the north, in the canyon below Middle Pass, the fold is well developed beneath the higher thrust slices. (See pl. 6, secs. *VI-VI'*, *VII-VII'*.) It involves the Martin limestone at the core. Although locally some small faults have thrust slivers of Cambrian rocks above the Martin, in general it is overlain normally by the Escabrosa limestone. On the western limb of the anticline, the Horquilla limestone appears to overlie the Escabrosa with depositional contact; but on the eastern limb of the fold, the Horquilla limestone on the south wall of the canyon seems to be a fault block, with the bedding within it striking nearly east, at a high angle with the trend of the fold.

In the high western spur and on the crest of Black Diamond Peak, this fold is overlain by two thrust sheets. The westerly and lower of these is composed of Horquilla limestone, forming a klippe resting on the west flank of the anticline. It is overridden by a higher plate of Escabrosa limestone, itself showing a low fold, which forms the crest of the peak and the spurs to the west and south for half a mile. As seen in the canyon on the southwest side of Black Diamond Peak, this plate is highly discordant, not only with the underlying fold outlined by the contact between the Martin and Escabrosa but with another thrust sliver of Horquilla limestone that lies in approximate conformity with the Escabrosa of the eastern anticlinal limb.

In the canyon southwest of Black Diamond Peak, the Martin limestone is well exposed at the core of the fold. The thickness is so great that there must have been some duplication, presumably by a thrust. Two small normal faults cut the west flank of the anticline, each dropping the north side a few scores of feet. In the next canyon to the south, in sec. 25, T. 18 S., R. 23 E. (unsurveyed), the Abrigo limestone is exposed at the core of a tight nearly isoclinal anticline. The Martin and Escabrosa limestones overlying it here exhibit the same anticlinal relations as to the north, but farther south only the eastern limb of the anticline is present.

It is perhaps significant that this anticline north of sec. 25 trends slightly west of north, about parallel to the Dragoon fault. To the south, the axis of the anticline is not identifiable, having been buried or cut off by faults along the west base of the range, but the homocline of early Paleozoic age that forms its eastern limb swings much more to the east again in parallel with the trace of the Dragoon fault. This swing conforms with other evidence in being consonant with an increase in the displacement of the Dragoon fault toward the south.

The fault that separates the Escabrosa and Horquilla limestones on the east limb of the anticline, beneath the thrust cap of Black Diamond Peak, seems to die out to the south and was not recognized in the canyon in sec. 25. However, as mentioned on page 143, a thrust emerges from the south side of the flat thrust cap at a higher stratigraphic level and brings the Horquilla limestone over the Earp formation on the east limb of the anticline. This fault dips steeply, nearly in conformity with the dip of the underlying rocks, though it crosscuts the strata at a low angle.

About 1,500 feet south of the thrust cap of Black Diamond Peak and due west of Dragoon Camp, this steeper thrust in the hanging wall of the Dragoon fault splits, the two branches enclosing a wedge of Colina limestone between the overlying Horquilla and the Earp of the lower block. About three-quarters of a mile farther south, this wedge narrows to less than 100 feet and from this point southward is composed of Earp formation. Also near this point the lower fault bounding the wedge transgresses the Horquilla and Earp boundary in the lower block, so that for the next mile to the south the Horquilla limestone forms the footwall of the steep eastward-dipping fault.

The fault wedge of the Earp formation terminates southward at a point about a mile northwest of Walnut Springs. The eastern fault bounding it continues southward, with Horquilla limestone in the hanging wall—the same relation as shown to the north—but the western fault is cut off obliquely by an overriding fault that dips steeply east and brings Escabrosa limestone over the end of the wedge of Earp formation. This body of Escabrosa limestone is less than a quarter of a mile long; the bedding within it dips only moderately, 40° eastward.

This small fault sliver of Escabrosa limestone is in turn cut off by a fault that brings a plate containing Abrigo limestone and the overlying Martin limestone above it. In the latitude of Walnut Springs the transverse section of the range thus includes, from west to east, a steeply northeastward-dipping homocline of early Paleozoic rocks overlain by a thrust sheet of nearly parallel dip that repeats the Abrigo, Martin, and Escabrosa limestones; this sheet is followed by a second eastward-dipping fault overlain by Horquilla limestone.

In sec. 4, T. 19 S., R. 24 E., the eastern and highest of these thrust sheets contains a body of monzonite porphyry, Copper Belle. The porphyry contact with the Horquilla and Escabrosa limestones to the northeast and east is clearly intrusive, but it is separated from the Escabrosa limestone on the southwest by the same fault that underlies the Horquilla plate farther north. (See pl. 6, sec. *X–X′*.) About a mile north of South Pass this easternmost of the faults in the Dragoon thrust block is cut off by the Dragoon fault.

The western fault, which repeats the rocks of early Paleozoic age, cuts lower in the section as it is followed to the south, and just northwest of the 6,520-foot peak in sec. 4, T. 19 S., R. 24 E., it brings Martin limestone in the eastern block against the same formation in the footwall. The top of this 6,520-foot peak is made up of a thrust plate of Bolsa quartzite, resting with a moderate easterly dip across the fault plane. This thrust outlier of Bolsa quartzite may be a remnant of the same plate as the one overlying the Colina mass in the salient of the Dragoon fault about 2 miles to the north-northwest. The outlier is less than 2,000 feet long. The buried thrust beneath this outlier emerges from its southeastern edge and can be traced to a junction with the eastern thrust about a quarter of a mile farther south. (See pl. 6, sec. *XI–XI′*.)

FAULTS ALONG WESTERN BASE OF THE MOUNTAINS

Most of the rocks exposed immediately above the alluvium that fronts the southwestern base of the mountains belong to the tectonic blocks previously described. At intervals from a point west of Middle Pass as far as the abandoned road through South Pass, however, outcrops of faulted rock masses are scattered—many of them tantalizingly small and poorly exposed. In view of the complexities of the structure in the well-exposed areas of the range, it is not surprising that a satisfactory synthesis of the structure in this poorly exposed area has not been reached; nevertheless, evidences of other thrusts as well as normal faults are clear-cut, though both their mutual relations and possible tectonic correlatives elsewhere in the area are largely conjectural.

The largest single exposure of these structural blocks lies immediately north of the mouth of the canyon west of Middle Pass. Here a body of the Earp formation lies on the Escabrosa limestone, with a low-angle westward-dipping fault contact. South of the canyon for 2 miles the alluvium masks the area beneath which this fault block probably continues. The fault block may be correlated with one of the two fault outliers of Carboniferous rocks on Black Diamond Peak. The only support for such a suggestion, however, is that the first fault block exposed in similar relations to the south is made up of Escabrosa and Horquilla limestones and may thus represent a southward continuation of the same block which farther north is represented by beds of approximately the same stratigraphic position. At any rate, the westward-dipping fault blocks near the common corner of Tps. 18 and 19 S., Rs. 23 and 24 E., rest on Bolsa quartzite and pre-Cambrian quartz monzonite belonging to the same structural block as the Escabrosa limestone at the mouth of the canyon below Middle Pass. The overlying block consists of Martin, Escabrosa, and Horquilla limestone, somewhat broken by faults but with a generally westerly dip.

A quarter of a mile farther southeast, in sec. 6, T. 19 S., R. 24 E., a mass of Bisbee formation lies, with a steep westerly dip, in the hanging wall of a steeper fault. Whether these Cretaceous rocks belong in the same tectonic block as the Paleozoic rocks to the north is impossible to determine.

Farther south the next exposures west of the body of Pinal schist that forms the lower slopes of the range are found in sec. 9, T. 19 S., R. 24 E. Here a small sliver of Gleeson quartz monzonite is exposed west of a high-angle fault that cuts the Pinal schist along an arcuate trace. At the next bedrock exposure this is followed by another slice of the Bisbee formation, also with a high-angle fault along its eastern contact. This Cretaceous body, however, is itself faulted and contains a wedge of Horquilla limestone. A similar block of Escabrosa limestone is faulted against the granite a few hundred feet farther south. Just north of the road through South Pass, a klippe of Horquilla limestone about 300 feet long rests on the pre-Cambrian granite. Its relation to other fault blocks can only be guessed at.

The recital of these relations suffices to show the impossibility of correlating the several fault blocks across the strike; their along-strike relations cannot even be satisfactorily worked out. Nevertheless, it seems worth while to point out that near Middle Pass the fold in the Paleozoic block to the east may reasonably be interpreted as genetically related to the dying out of the Dragoon fault. Accordingly, the thrust sheets of Black Diamond Peak may owe their lower dip to this folding and be not unreasonably correlated with the westward-dipping fault sheets on the west foot of the range in this latitude. Farther south, however, though the eastern limb of the anticline in the Dragoon block is continuous with that to the north, the western limb is missing. The anticlinal plunge is northward; for several miles north of South Pass, the fault blocks on the west flank of the range must thus be interpreted as cutting deeply into the tectonic block to the east. They may represent upthrusts through the Dragoon block (of the sort that that block itself is believed to be), wholly exotic fragments from higher thrust sheets, or possibly parts of the missing western flank of the Dragoon block itself. Which of these possible interpretations is to be made seems highly subjective; actual evidence compelling one interpretation rather than another has not been recognized if it is present.

STRUCTURAL FEATURES EAST OF THE DRAGOON FAULT

AREA FROM MIDDLE PASS TO VICINITY OF DRAGOON CAMP

Immediately east of the Dragoon fault throughout this segment of the range, is a body of the Bisbee formation. (See pl. 13.) For the most part it includes limestone conglomerate along the fault and dips steeply eastward, though locally the dips are as low as 25° NE. and elsewhere the beds are overturned to dips as low as 50° SW. The ridge immediately south of Middle Pass is made up of limestone conglomerate of the Bisbee, dipping 30° to 50° E. A northward-dipping fault crosses this ridge and cuts off the conglomerate in the Bisbee. To the west this fault also cuts the Dragoon fault and can be traced for more than half a mile by its offset of the flat thrust sheet capping Black Diamond Peak. Eastward, however, it has not been recognized beyond the point where both walls are composed of the Bisbee formation; it has, rather arbitrarily, been mapped as ending with the northerly fault next to be described.

Exposures of the fault block that lies in Soren's Canyon and is composed of Cochise Peak quartz monzonite and locally overlying Bolsa quartzite and Bisbee formation terminate south of Middle Pass at a northeastward-trending fault. The limestone conglomerate on the strike of this block south of the fault appears to be separated from the Bisbee formation to the east along a line (mapped on pl. 5 as a fault) on strike with the eastern boundary of the thrust block to the north. The brush, talus, and absence of distinctive beds within the Bisbee combine to obscure these relations, and it is highly probable that no fault would have been mapped here were it not for the clear-cut evidences of faulting both to the north and south. These evidences at more northerly localities have already been described (see p. 143); those to the south are likewise convincing.

Due east of Black Diamond Peak, clear-cut faults are found on the strike of each of the faults bounding the block of Cochise Peak quartz monzonite to the north. Between the Dragoon fault and the western of these, a strip of Bisbee formation stands nearly vertically. The western fault is also nearly vertical, as well as can be determined; it is followed to the east by a block of granite and Pinal schist, overlain, with apparent depositional contact, by Bolsa quartzite. The eastern fault, bounding this block, is also steep but locally, at least, dips westward. East of this steep fault is a large body of Bisbee formation within which the dips are generally eastward at angles ranging from 20° to 70°, but with some local reversals.

The block of crystalline rocks and Bolsa quartzite continues southward to Dragoon Camp, with the bounding faults maintaining their high angles. At Dragoon Camp a sliver of limestone, believed to be Escabrosa, appears as a narrow horse in the western fault. It can be traced for nearly 2,000 feet as a belt 200 feet or less in width, terminating in the canyon at Dragoon Camp. The wedge of limestone has been mineralized and, though the mine openings are no longer accessible, has obviously been extensively explored. Exposures in the canyon to the south and east of the adits are poor. However, a fairly continuous exposure of altered sandstone and shale occurs on the lower north slopes of the canyon, beneath the Pinal schist and its cap of Bolsa quartzite. The contact is obscure but seems to be almost horizontal; it is interpreted as a fault, surely confined to the block between the high-angle faults just described and older than they, as beds in the Bisbee, both to the east and west, can be traced continuously across its projected trace. It is interpreted as a thrust—probably the same one as is exposed at the Cobra Loma prospect 3½ miles to the north, beneath the Cochise Peak block.

The western of the high-angle faults bounding the Dragoon Camp block must swerve sharply eastward either in the canyon at the camp or the next one to the south, but as the Bisbee formation is on both walls, it was not accurately located on the scale of plate 5. Low on the next spur to the southeast, however, it is well exposed, with Bisbee strata to the west and pre-Cambrian crystalline rocks to the east. Similar relations are found for the next mile or so along the foothills, as far as sec. 33, T. 18 S., R. 24 E. On two of these low spurs Cretaceous rocks are clearly seen to underlie the pre-Cambrian remnants, a fact that confirms the interpretation of the less well exposed contact of Pinal schist and Bisbee formation at Dragoon Camp as a thrust fault. The geometrical implications of these observations can best be discussed in the light of the structures of the Cretaceous rocks to the east and west of the Dragoon Camp fault block.

STRUCTURAL FEATURES OF THE BISBEE FORMATION

As mentioned in the description of the Dragoon fault, the Bisbee formation in the block between this fault and the crystalline rocks of Dragoon Camp dips generally at very high angles or is overturned and dips westward. These relations prevail beyond the termination of the Dragoon Camp faults as far as South Pass, in the immediate footwall of the Dragoon fault. For long distances limestone conglomerate crops out along the fault and strongly suggests that the base of the Bisbee formation is not far beneath the fault on the footwall side.

The Bisbee formation to the east of the Dragoon Camp block shows much lower easterly dips of 50° to 15°, with local reversals near Middle Pass. These attitudes prevail in all the area northwest of a line drawn from Pearce southwestward to the end of the exposure of crystalline rocks of the Dragoon Camp block. Southeast of this line as far as a line from South Pass to the hills north of Courtland, although there are a few areas of steep northeasterly dips, most of the beds are overturned, some to angles as low as 25° SW. No faults were observed to separate the areas with these contrasting attitudes, and a sufficient tracing of individual beds practically eliminated their possible existence, except in the area near Barrett Camp.

STRUCTURAL INTERPRETATION

The only reasonable interpretation of these relations that has occurred to me is the following: The Bisbee formation in this area forms a plunging syncline, overturned so far as to cause the axial plane to lie flat or even dip eastward though the fold closes to the west. Toward the north, only the upright lower limb is exposed. Southward the plunge of the fold carries the lower limb out of sight along a line from Pearce southwestward to a point about 2 miles southeast of Dragoon Camp. The overturned beds to the southeast belong in the upper limb, except for the segment nearest the Dragoon fault where steeply eastward-dipping, vertical, and slightly overturned beds mark the zone of the fold axis. It is noteworthy and significant that the tops of all the Cretaceous strata east of the mountains face eastward, except for those in a narrow zone east of Barrett Camp and those near the mouth of Middlemarch Canyon. This overturning involves a section not less than 15,000 feet thick, for the continuity of the beds denies the possibility of any important duplication by faulting.

The interpretation of the structural features northeast of the Dragoon fault is thus controlled by the following salient facts:

1. The Dragoon fault dips westward at angles that become progressively lower from north to south.
2. The Bisbee strata exposed immediately along the fault are stratigraphically near the base of the formation.
3. The Dragoon Camp fault block is bounded by high-angle faults on both sides as far south as Dragoon Camp and on the west for at least 2 miles farther.
4. The base of the block of pre-Cambrian crystalline rocks in the Dragoon Camp block is a low-angle thrust fault whose footwall is composed of Bisbee formation.
5. The Dragoon Camp fault block is on strike of a thrust sheet whose basal fault east of Cochise Peak dips westward at an angle of about 60°.
6. The Bisbee formation east of the Dragoon Camp block seems to form a strongly overturned syncline, plunging to the south; on the strike of this block no break has been recognized within the Bisbee formation beyond a point a mile or so southeast of the end of the exposure of crystalline rocks.

Sections *V–V′* through *XI–XI′*, of plate 6, show the interpretation placed upon the surface data reviewed above. The first synthesis attempted involved the assumption that the crystalline rocks of the Dragoon Camp area constitute a segment of a higher thrust plate, dropped into the Bisbee rocks along a graben. Section *VIII–VIII′* on plate 6, taken by itself, could be more readily drawn in this way than in the manner finally adopted. However, such an interpretation cannot possibly be made consistent with the surface observations farther north, and the attempt to carry it through sections *VI–VI′* and *V–V′* on plate 6 resulted in absurdity. The interpretation finally adopted and shown on plate 6 seems farfetched, it is readily granted. The rapid southward wedging out of the Dragoon Camp block is difficult to reconcile with its being an upthrust or up-squeezed mass, as one would be justified in expecting a strong southerly plunge of the component rocks at the end of the wedge. Nevertheless, the southward plunge of all the structurally lower thrust sheets east of Middlemarch Canyon is clearly evident. The Cochise Peak block partakes of this plunge, at least in the latitude of Middlemarch Canyon. The small transverse faults cutting this fault block near Middle Pass do not seem to permit any other interpretation than that the Cretaceous block to the west is continuous with the one that overrides the Cochise Peak block at Soren's Camp. It is tectonically higher, not lower, than the block to the east. The Escabrosa limestone at Dragoon Camp must therefore have been dragged up from below rather than dropped from a higher level. Similarly the Cretaceous rocks to the east of the Dragoon Camp block belong to a tectonic unit lower than the block. It seems possible for them to have acquired their present position only by vertical movement along the eastern fault bounding the Dragoon Camp block. A steepening of the eastern fault by warping alone should surely be reflected in comparable warping of the Cretaceous rocks to the east of this fault; that is, their dips should become flatter to the south rather than steeper, as they clearly do. Accordingly, though a more detailed study may well reveal significant relations that were overlooked during the mapping on the scale of plate 5, it seems that the difficulties in the way of accepting the interpretations of plate 6 are less than those confronting all the alternatives considered.

AREA FROM SOUTH PASS TO NORTH COURTLAND

THE DRAGOON FAULT

In contrast with the relatively regular course of the Dragoon fault farther north, in the neighborhood of South Pass it not only curves abruptly eastward but is offset by several faults and involves so many fault slivers as to constitute a fault zone rather than a single, clean-cut fracture. (See pl. 13.) The complexity of this zone is such as to require separate treatment; in this section attention will be confined to the most southerly and westerly boundary faults which separate the block of Gleeson quartz monzonite from the complex zone.

As thus defined, the Dragoon fault in the valley of South Pass separates the Gleeson quartz monzonite from andesites of probable pre-Cretaceous age. The fault dips westward about 45°. That the Pinal schist and overlying Cambrian rocks terminate southward against the Gleeson quartz monzonite of the hanging wall block (in the stream immediately opposite a sharp curve in the fault trace) suggests that there might be a transverse fault in the hanging wall block. No evidence of such a fault could be found.

Within 200 yards southeast of the road, a northeastward-trending fault offsets the Dragoon fault nearly 1,000 feet. The direction of shift of the Dragoon fault outcrop suggests that the southern wall has been relatively uplifted or shifted southwestward, but the attitude of the northeasterly fault was not determined.

Beyond this offset the Dragoon fault continues southward for several hundred feet, then turns abruptly eastward. At the angle a block of Colina limestone is in the footwall. Just east of the angle the fault is offset a few hundred feet by a northward-trending fault. Here the Dragoon fault and the adjacent sliver of Colina limestone dip about 50° S. The footwall is a mass of breccia, more than 1,000 feet wide, in which all the Paleozoic formations are represented along with slices of Bisbee formation, andesitic and rhyolitic volcanic rocks, and Gleeson quartz monzonite. The mapping of plate 5 is highly generalized in this area as the scale permits showing only the largest of these fault slivers.

At about the center of sec. 14, T. 19 S., R. 24 E., the Dragoon fault is offset half a mile to the north by a high-angle fault. This younger fault can be followed for more than 2 miles to the south by the breccia along it; to the north it can be traced clearly for about half a mile by the abrupt boundary between andesitic volcanic rocks and Bisbee formation, before swinging to a more northwestward trend. East of this northward-trending fault, the Dragoon fault makes a relatively clean-cut contact between Bisbee formation and Gleeson quartz monzonite for about half a mile, though it is offset several hundred feet by a northwestward-trending fault.

Near Barrett Camp, however, a breccia zone begins in the footwall and continues along it for nearly 2 miles. Along this segment the Dragoon fault dips southward at angles that are locally as low as 30° but probably average about 50°. The astonishingly continuous thin slivers in the breccia zone of the footwall—some more than half a mile long and less than 300 feet wide—dip somewhat more steeply than the Dragoon fault itself, and some of them are vertical. They include recognizable representatives of all the Paleozoic formations except the Martin limestone and Earp formation, both of which are so shaly that they have doubtless been sheared beyond recognition. These rocks occur in random stratigraphic order, but it is noticeable that the rocks of earlier Paleozoic age are relatively more abundant near Barrett Camp and younger formations predominate toward the east. In the northwestern part of sec. 18, T. 19 S., R. 25 E., the plates composing the breccia dip at much lower angles, the most easterly of the limestone masses in the zone having a dip of 20° or less.

In the northeastern part of sec. 18, although much of the Dragoon fault trace is concealed by alluvium, a small salient of Gleeson quartz monzonite lies on the north wall of the creek, with a low-angle fault contact well exposed beneath it. The outcrop pattern of the fault to the east of this creek strongly suggests a low dip. In the northeastern corner of this section, the fault outcrop swings south. It is offset by two easterly faults, so that an oblong exposure of Bisbee formation extends westward into the Gleeson quartz monzonite. These offsetting faults are small, as their strike extent is slight. The deep indentation they produce in the trace of the Dragoon fault thus suggests a low dip for the fault in this angle—a suggestion that is further supported by the breccia and mylonite of Gleeson quartz monzonite that prevails here for more than a thousand feet west of the fault trace.

STRUCTURAL FEATURES EAST OF THE DRAGOON FAULT NEAR SOUTH PASS

The structural relations of the rocks in the footwall of the Dragoon fault, in the triangular area roughly outlined by South Pass, Barrett Camp, and Walnut Springs, offer one of the most puzzling problems in the region. A satisfactory interpretation is hampered because the identification of the rhyolitic and andesitic volcanic rocks and associated sediments at South Pass as pre-Cretaceous is by no means proved.

A fault lying in the footwall of the Dragoon fault can readily be traced from a point near Walnut Springs to a point a mile west of Barrett Camp. For the most part it is nearly vertical but in several places dips 70° westward. Near Walnut Springs it separates sandstone and fine conglomerate on the west from coarse limestone conglomerate on the east. Northward this fault is lost under the alluvium, but if prolonged in strike it would intersect the Dragoon fault in the western part of sec. 31, T. 18 S., R. 24 E. For nearly 2 miles south of Walnut Springs, the fault is marked by both the sharply different lithologic characters of the Bisbee rocks on the two sides and by abrupt differences in local attitude. No measure of the displacement along it is possible, however, as no individual strata have been recognized on both sides of the fault.

At a point about a mile northeast of South Pass, this fault is joined by another that, though the junction is concealed by alluvium, must intersect it at nearly a right angle. This northeastward-trending fault separates andesite on the south from the Bisbee on the north. Though the attitudes recognized in the volcanic rocks and associated tuffaceous sedimentary rocks are variable, they contrast sharply with that of the Bisbee, which is nearly uniformly steep to overturned.

Immediately southeast of this junction, a low knob on the pediment marks a horse of Escabrosa limestone in the northwestward-trending fault between the volcanic rocks and the Bisbee formation. The limestone mass dips steeply west, perhaps indicating a similar attitude of the fault. A short distance farther southeast, the fault swings to a nearly southerly trend, which it maintains for nearly 2 miles.

As shown by the offset of the southward-dipping Dragoon fault, the rocks to the west must have moved relatively upward or southward with respect to those on the east of this northward-trending fault. This would make tenable the supposition that the fault may join the Dragoon fault at the north and represent a late branch of this master fault despite the fact that west of Barrett Camp its trend is nearly normal to that fault. Whether it does in fact join the Dragoon fault at the north, as its course where traceable would suggest, is uncertain because of alluvial cover and the difficulty of recognizing a high-angle strike fault in the steeply dipping rocks of the footwall of the Dragoon fault. On the other hand, the relation of the fault to the breccia along the Dragoon fault west of Barrett Camp, which it cuts at right angles, proves that most of the displacement along the southern segment was later than the Dragoon fault. Much more detailed mapping than was possible on the scale of plate 5 would be required to solve this problem.

The small body of Bisbee formation, apparently a klippe, resting on the pre-Cretaceous volcanic rocks in the SW¼ sec. 11, T. 19 S., R. 24 E., does not seem to be related to any other of the local fault blocks. It rests on a fault of probably low dip; all the other faults nearby are much steeper.

STRUCTURAL FEATURES NEAR NORTH COURTLAND

From Middle Pass to Barrett Camp the attitude of the Bisbee rocks in the footwall of the Dragoon fault is consistently related to that of the fault. Throughout this distance the strike of the beds is closely parallel to that of the fault, and the dip ranges from steeply east to overturned west—relations that strongly suggest a genetic connection between the fault and the present bedding attitudes. The relations are appropriate for the folding to be interpreted as due to fault drag on a huge scale. Near Barrett Camp the strike of the Bisbee strata swings abruptly from about N. 30°–45° W. to N. 75°–90° E., but this is approximately conformable to the Dragoon fault and again can be attributed to drag along the transcurrent part of this fault.

A mile east of Barrett Camp this regularity in structure and the accordant relation to the Dragoon fault both are lost. In the S½ sec. 7, T. 19 S., R. 25 E., the Bisbee strata are highly contorted and strike at right angles into the Dragoon fault. The small mass on the south line of sec. 8 of the same township actually dips southward, with the tops of the beds facing toward the fault. A half mile northeast, the Bisbee rocks on the line between secs. 8 and 9 strike nearly north at the west base of the butte, but they are upright and appear to be separated by an unconformity rather than a fault from the volcanic rocks capping the butte shown as Sugarloaf on plate 5. These are the most southeasterly exposures in the Dragoon Mountains of rocks that can be unequivocally assigned to the Bisbee formation. The several small bodies shown on plate 5 and on the sketch maps of the Courtland-Gleeson area, plates 11 and 12 and figures 7–9, as belonging to the Bisbee are largely of the limestone conglomerate or maroon mudstone facies and are nearly or quite indistinguishable lithologically from known postthrusting sedimentary rocks found widely in the area. The assignment of these small masses to the Bisbee is largely justified on the basis that they are involved in the thrust breccias and the Bisbee is the only known formation with this lithology that is older than the Dragoon thrust. The possibility that these small masses may belong to some epoch subsequent to the Bisbee yet earlier than the thrust cannot be eliminated on available evidence.

The eastward-trending branch of the Dragoon fault is exposed only in the NW¼ sec. 17, T. 19 S., R. 25 E. Its extension eastward is inferred from the areal distribution of the Paleozoic plates on the south, on the strike of the Bisbee, and volcanic rocks just mentioned. In view of the relations of the Bisbee strata to the north, it seems that only a small fraction of the displacement of the Dragoon fault farther west and south need be postulated for this fault. It is probable, for example, that the Bisbee rocks in secs. 7 and 8 belong on the upright limb of the overturned syncline to the north and that the Sugarloaf quartz latite of the North Courtland Hills are in essentially normal position in the axis of this syncline. The Dragoon fault to the west transects the overturned limb—to the south it cuts the upright limb and the older thrust sheets that there overlie the volcanic rocks.

COURTLAND-GLEESON AREA

GENERAL STATEMENT

The most complex part of the area mapped on plate 5 lies in the Courtland-Gleeson mining area. Here the Dragoon fault separates the great block of Gleeson quartz monzonite forming the southern Dragoon Mountains from a plexus of small fault blocks that makes up the eastern hills and lower slopes. The block west of the Dragoon fault, though somewhat broken, is essentially a unit, so far as known; but east of the fault the individual fault blocks are so small that their representation must be generalized on maps of the scale of plate 5 and even on that of plate 11. Time did not permit the preparation of a controlled map of scale adequate to show the geology in detail; the sketch maps of plates 11 and 12 and figures 7–9 illustrate some of the relations observed.

It is hardly an exaggeration to say that in the Courtland–Gleeson area more than 90-percent of the total linear extent of the bedrock contacts east of the Dragoon fault are mechanical. The rocks of Paleozoic age and small local bodies of Pinal schist and other rocks are jumbled in almost random stratigraphic order in a gigantic breccia overlying the Sugarloaf quartz latite, Copper Belle monzonite porphyry, and Turquoise granite.

THE DRAGOON FAULT

From the sharp salient in the NE. cor. sec. 18, T. 19 S., R. 25 E., the trace of the Dragoon fault turns southward. It is concealed by alluvium for more than a mile, though outcrops of Cambrian rocks and Turquoise granite on the east and of Gleeson quartz monzonite on the west enable it to be closely bracketed. In the SW¼ sec. 20, T. 19 S., R. 25 E., the fault emerges from the alluvial cover and can be followed for nearly a mile of its course, though it is not well exposed because of colluvium. Its trace over the topography suggests that in this section it dips westward at a rather steep angle, though the actual fault plane was not seen. In part of this segment, the fault seems to be occupied by a dike of felsite probably related to the Stronghold granite (not mapped). In part, the irregularity of the fault trace beneath the alluvium may be due to sinuosity of the fault, in part to offsets by concealed cross faults, and in part to strike faults that have dropped the Dragoon fault, so that it fails to crop out. From the map pattern the Gleeson quartz monzonite to the west is obviously separated from the fault complex and Sugarloaf quartz latite to the east by faults for the next several miles to the south, just as to the north of this cross fault, but in some places the exposed faults appear to be vertical or even to dip eastward, so that they are considered younger faults that have cut the Dragoon fault itself. For example, in the SE¼ sec. 30, T. 19 S., R. 25 E., the fault separating the Sugarloaf quartz latite from the Gleeson quartz monzonite dips eastward about 30°. It seems geometrically impossible for this to represent the Dragoon fault. It is accordingly interpreted as a minor thrust that has overridden the Dragoon fault, so that the Dragoon fault lies concealed in the footwall of the eastward-dipping fault. Very slight displacement is all that would be needed to bring this about—perhaps 100 yards. On the other hand, no similar thrusting later than the Dragoon fault has been identified elsewhere in the area. This interpretation is supported by the fact that the quartz latite in the hanging wall of this eastward-dipping fault rests on a westward-dipping fault that causes it to overlie Abrigo limestone and Escabrosa limestone in a manner exactly analogous to that seen a mile farther south. At this southern locality, west of the Copper Belle mine, near the center of sec. 32, T. 19 S., R. 25 E., the quartz latite is in turn overridden by Gleeson quartz monzonite on a well-exposed fault that dips steeply west. This steep fault is regarded as a segment of the Dragoon fault.

From a point southwest of the Copper Belle mine, in the SW¼ sec. 32, T. 19 S., R. 25 E., the Dragoon fault disappears beneath the alluvium, and farther southward extension is concealed. It is inferred, of course, to pass eastward of the small outcrop of Gleeson quartz monzonite in the southern part of sec. 31, T. 19 S., R. 25 E., and through the narrow saddle between the knob of Bolsa quartzite and Gleeson quartz monzonite in the NW¼ sec. 5, T. 20 S., R. 25 E. In the southwest quarter of the same section it can be closely bracketed between the Sugarloaf quartz latite to the east and the Gleeson quartz monzonite to the west; both formations show conspicuous reddening nearby, but the fault itself is concealed by float. Along the western base of Sugarloaf Hill the boundary between lava and intrusion can be closely located, but here again it is not exposed. The Sugarloaf quartz latite to the east is considerably sheared and reddened near the contact. The dip of the shear zones is low to the east, about parallel to the dip of the volcanic rocks; and taken by themselves these observations might more readily be interpreted as suggesting an eastward-dipping fault, with the volcanic rocks resting on the quartz monzonite. Such an interpretation would seem to require, however, that the Dragoon fault has been dropped out of sight beneath the western block rather than being represented by the exposed fault that dips eastward. In view of the abundant evidence of low-angle faults to the east of the Dragoon fault both here and farther north, it seems more reasonable to regard the eastward-dipping shears in the volcanic rocks as related to these older faults rather than to late movement on the Dragoon fault. When the structure of the entire Courtland–Gleeson area is considered, it does not seem that such an interpretation constitutes special pleading, as it perhaps would were attention confined to these local relationships.

COURTLAND AREA

The fault that trends northeast and east through the northern part of sec. 17, T. 19 S., R. 25 E., may well be a lower branch of the Dragoon thrust. Though largely concealed by alluvial deposits, it brings Escabrosa limestone over the Bisbee formation on a low hill in the NW½ sec. 17 and must turn southeastward near the northeast corner of this section, where Copper Belle monzonite porphyry and Horquilla limestone rest on Bisbee formation.

Though alluvium prevents tracing this fault to a junction with the main Dragoon fault, this fault clearly must be related to the Dragoon fault as it separates Paleozoic and older rocks from Bisbee rocks that seem in normal attitudes, implying that they are perhaps 15,000 feet above the normal position of the Paleozoic. Whether the fault plexus to the south, next to be described, is analogous tectonically to the gigantic breccia of Paleozoic and Mesozoic rocks lying between Middlemarch Canyon and the Stronghold granite 10 miles to the northwest or to the eastward-dipping thrust slivers of the Dragoon Mountains just north of South Pass cannot be decided from the data at hand. Indeed, these two blocks may be tectonically alike and merely cut and displaced by the Dragoon thrust. There is even a possibility that this obscure fault is the main branch of the Dragoon fault and extends south beneath the alluvium to the east of the main bedrock exposures. More detailed studies of the volcanic rocks in the hills in secs. 4 and 8, T. 19 S., R. 25 E. (which, though mapped as Sugarloaf quartz latite, may not be), and of the Bisbee strata to the west and northwest of them may enable a better judgment than the present data. On the basis of this survey the question must be left open.

A glance at the geologic map of the Courtland area (pl. 11) suffices to show the complexity of the structure to the south of the fault just described. The discrimination of the formations, especially on Turquoise Ridge and Brown's Peak, is rendered difficult by rock alteration, owing to hydrothermal metamorphism and weathering of the highly pyritic material that is so widespread in these rocks. The sulfuric acid formed during weathering has altered the rocks so drastically as to render dubious the distinction even between such originally different formations as the Abrigo limestone and the Copper Belle monzonite porphyry; the original character of the Turquoise granite can only be surmised. These facts have been commented upon by both Ransome (1913, p. 127, 129, 133) and Wilson (1927, p. 46), and are here recalled because of my inability to discriminate consistently between the Sugarloaf quartz latite, the Turquoise granite, and the apparently subordinate quartz porphyry intrusions recognized by both Ransome and Wilson, as well as myself. This has resulted in certain admitted inconsistencies in the mapping of plate 11, which locally shows Sugarloaf quartz latite in intrusive contact with the Paleozoic rocks. These small bodies of intrusive rock are undoubtedly younger than the Sugarloaf quartz latite and perhaps younger than the thrusting; nevertheless, they could not be distinguished from the overwhelmingly more abundant quartz latite when traced into it along their strike. For this reason, it seems preferable to map the felsitic porphyries as part of the Sugarloaf. Mapping on a scale far larger than that of plate 5 (the field scale) would be necessary to eliminate these inconsistencies, which are repeated in the enlarged sketch maps (pls. 11 and 12).

Owing to the rock alteration just described and to the widespread and intense brecciation of most of the rocks of the Turquoise Ridge–Brown's Peak area, it has not been possible to relate many of the individual fault blocks to the regional structure. Many of the fault blocks on the crest and west slope of this ridge appear to have steep bounding faults; others, such as those in the SW. cor. sec. 17, have low-angle faults separating them. So far as could be determined, however, all these fault blocks are structurally higher than the Turquoise granite, which seems to represent the lowest tectonic level exposed east of the Dragoon fault. It should be pointed out that the outcrop width of the much jumbled blocks of Bolsa quartzite is considerably greater than can be accounted for without much faulting. Many faults are to be seen locally on the northern part of the ridge, but the considerable amount of rubble and talus and the absence of distinctive beds in the quartzite prevent tracing them. The west slopes of the ridge expose, though poorly, enough of the contact of the Turquoise granite with the Bolsa and Pinal to show that this contact is frozen. Accordingly, if the faults in the canyon between Turquoise Ridge and Brown's Peak and on the northern part of Brown's Peak extend southward, they must lie on the eastern slope, where they could not be traced.

The relations are considerably clearer, though still complex, on the eastern side of Turquoise Ridge (pl. 12). Beginning at the north, it is possible to trace the boundary between the Abrigo limestone and the Copper Belle monzonite porphyry as a well-defined fault, which dips westward about 10°, with a strong friction breccia developed along it. The narrow wedge of Abrigo lying to the east of this fault constitutes a sliver between two blocks of the porphyry. These rocks are overridden to the southeast by an eastward-dipping thrust which carries Martin limestone and Escabrosa limestone over both the narrow sliver of Abrigo and the westward-dipping thrust beneath the Bolsa and Abrigo block that makes up the eastern slopes and crest of Turquoise Ridge. About 2,000 feet to the southeast the overriding block above this eastward-dipping fault has been removed by erosion, so that the underlying rocks emerge from beneath it. Both here and to the north of the thrust cover, the Abrigo limestone overlies the porphyry on a low-angle thrust. Exposures are rather poor for about 1,000 feet farther along this contact, and where the boundary can again be seen well, near the south line of sec. 17, it is formed by a steep westward-dipping fault. This fault, which must surely be interpreted as normal, drops the low-angle fault out of sight in the hanging wall. It is offset slightly by a northeast fault just north of the section line, whence it can be traced southeastward to the end of the porphyry outcrop. The Escabrosa block west of Casey Hill (at the common corner of secs. 16 and 20, T. 19 S., R. 25 E.) which is clearly thrust over the porphyry to the north, appears to be cut off by a steep fault from the Abrigo limestone to the west. This would imply, on the assumption that the high-angle bounding fault is the same as the one to the northwest just described, that it has become pivotal, with downthrow on the east in the segment west of Casey Hill, for the Escabrosa block is almost surely a part of the same thrust plate that to the north rests on the Abrigo plate. Of course, the fault west of Casey Hill is possibly a different one whose strike continuations are not traceable because of poor exposures. It seems unnecessary to postulate more than a few score feet of displacement in order to yield the outcrop pattern seen. No thrust exposed farther south seems reasonably to be correlated with the one at the base of the Abrigo along the east base of Turquoise Ridge.

The east slope of Brown's Peak exposes a highly complex structure. (See pl. 8.) Several well-exposed fault outliers of Bolsa quartzite rest on Sugarloaf quartz latite and Abrigo limestone. The quartz latite (and possibly the undifferentiated intrusive felsite) has been thrown into tight folds, overturned eastward, one with a core of Abrigo limestone. None of these features could be traced sufficiently far to ascertain their relations to the structures to the north and south. It is possible that the Bolsa remnants were formerly continuous with the plate of Bolsa described in the following paragraph.

The most striking structural features of the Courtland area are the low-angle thrust faults in secs. 16, 17, and 21. (See pl. 12.) The thrust underlying the Bolsa quartzite is shown on the maps of both Ransome and Wilson, who point out that the thrust has been cut and displaced by later high-angle faults. Inasmuch as neither of these geologists attempted to subdivide the rocks of late Paleozoic age, the faults between the Escabrosa and Horquilla and that which brings the Colina limestone over the Sugarloaf quartz latite and Horquilla limestone were not distinguished on their maps.

Both Ransome and Wilson regarded the Copper Belle monzonite porphyry of this report (quartz monzonite of Wilson, monzonite porphyry of Ransome), as a postthrust intrusion. The low-angle fault in sec. 17, described in an earlier paragraph and shown on plate 12, that brings Abrigo limestone over the porphyry shows a marked friction breccia along it. This low-angle fault seems clearly to belong to the same group of thrusts as the stratigraphically obvious one that brings the Cambrian over the Horquilla to the east. Narrow slivers of highly sheared rock, recognizable as Copper Belle monzonite porphyry, occur between the thrust plates of Colina and Horquilla limestones on and just west of the eastern line of sec. 21. (See pl. 12.) A similar low-angle fault separates the monzonite porphyry from the overlying Escabrosa limestone in the area about 1,000 feet east of the west boundary of sec. 21, just west of the high-angle northwestward-trending fault shown on plates 11 and 12. The well-exposed contacts of the body of Sugarloaf quartz latite whose southern tip is about 900 feet north of the center of the south line of sec. 16 are both formed by low-angle faults, again showing that the underlying quartz monzonite porphyry is older than the thrust. Further evidence is afforded by the sheared slivers of Copper Belle monzonite porphyry between the thrust plate of Bolsa quartzite and the underlying Horquilla limestone in the NW. cor. sec. 21. All these features are consistent in pointing to a prethrust age of the Copper Belle monzonite porphyry in the vicinity of Courtland. It is a very striking fact that the maps by both Ransome and Wilson fail to show a single place where the supposedly postthrust porphyry has cut a thrust fault, though it is shown as abutting the thrusts in several places. Accordingly, it seems certain that the porphyry antedates the low-angle thrusts.

GLEESON AREA

(Pls. 11 and 13 and figs. 7-9)

The dominant elements of the geologic structure near Gleeson include the relatively large thrust plates resting on the Copper Belle monzonite porphyry of Gleeson Hill, the highly confused mass of much smaller blocks that crop out in the low hills to the eastward, and the block of eastward-dipping homoclinal Sugarloaf quartz latite of the Sugarloaf Hill area.

Gleeson Hill exposes a nearly complete ring of outcrops of Copper Belle monzonite porphyry around its lower slopes. The porphyry is overlain by a plate of Escabrosa limestone, upon which, in turn, rests a mass of Horquilla limestone. This order is, of course, a normal stratigraphic sequence, and although it is a reasonable working hypothesis that the Copper Belle monzonite porphyry has here invaded an eastward-dipping body of Carboniferous rocks, that this is not the actual situation seems highly probable, if not proved, by the following facts:

1. Friction breccias are exposed along the nearly flat

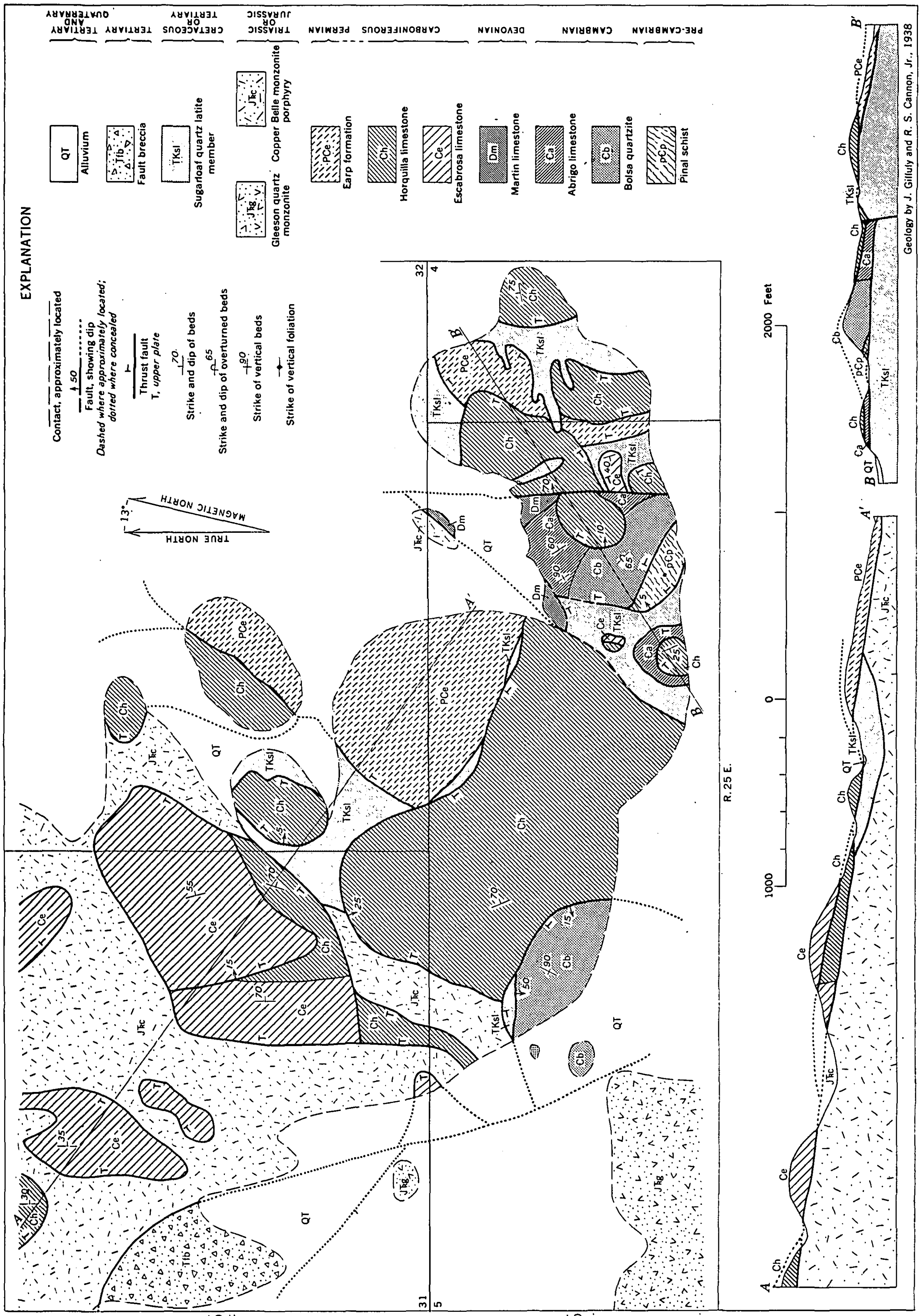

FIGURE 7.—Sketch map of area east of Gleeson, illustrating representative relationships in the thrust breccia of the Courtland-Gleeson area.

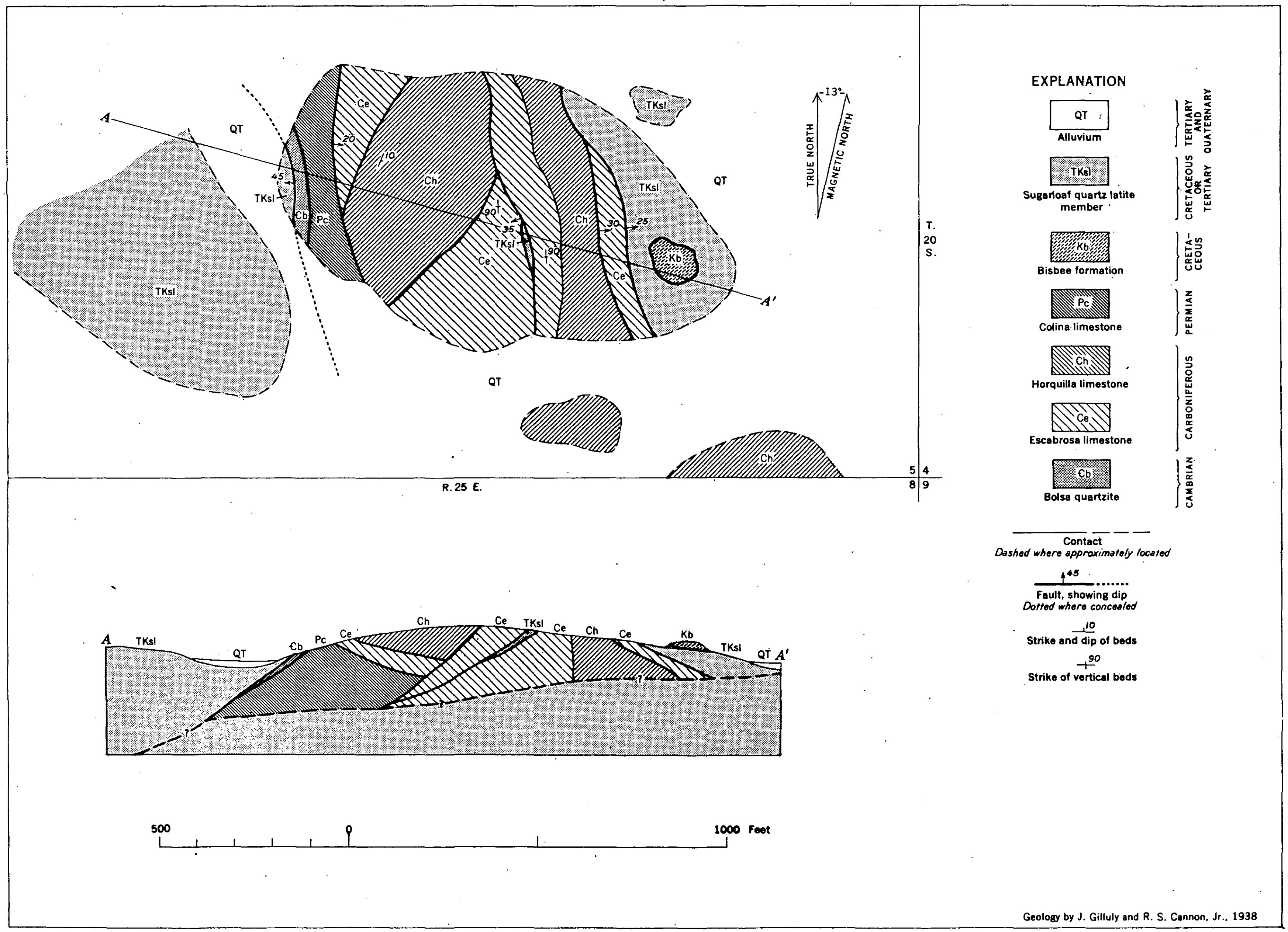

FIGURE 8.—Sketch map of area northeast of Sugarloaf Hill, illustrating representative relationships in the thrust breccia of the Courtland-Gleeson area.

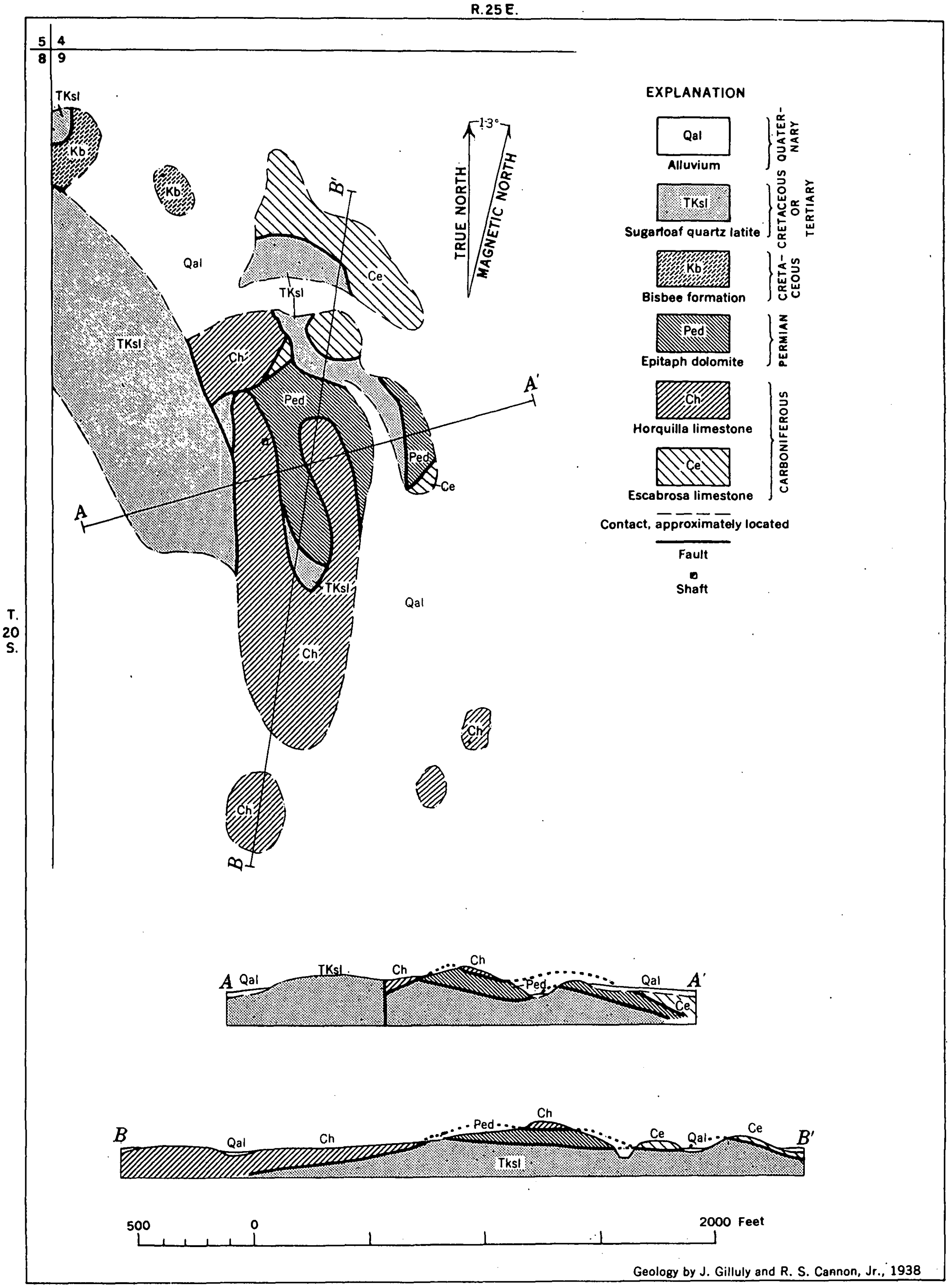

FIGURE 9.—Sketch map of area east of Sugarloaf Hill, illustrating representative relationships in the thrust breccia of the Courtland-Gleason area.

basal contact of the Escabrosa limestone; near the southeastern end of the ridge; on the southwestern slope above the old Tejon shaft, near the center of sec. 32, T. 19 S., R. 25 E., where rhyolitic tuff also is exposed between the limestone and porphyry; directly east of the site of the old Gleeson railroad station, where the Escabrosa rests on Sugarloaf quartz latite as well as on the Copper Belle monzonite porphyry; at the northern end of Gleeson Ridge, where the limestone, much mixed with sheared tuff, rests on the Copper Belle monzonite porphyry; at many points along the northeast side of Gleeson Ridge, where the contact is well exposed by prospect pits. Unmetamorphosed friction breccias containing foreign rocks along flat faults also occur within the Copper Belle monzonite porphyry on the east flank of the ridge and all but prove the porphyry to be involved in the thrusting.

2. Although the Horquilla limestone dips eastward at angles as high as 50°, the basal contact of the Horquilla hardly deviates 100 feet from the 5,300-foot contour around the ridge, so that the boundary between the Horquilla and underlying Escabrosa is strongly discordant over the area as a whole. At many places exposures are clear enough to show that the boundary is a fault, varying only a few degrees from the horizontal. At least one higher fault, dipping west about 10° brings a thin plate of Horquilla limestone over the strongly discordant lower plate of the same formation at the crest of the knob on the line between secs. 29 and 32.

Along the southwestern flank of Gleeson Hill is a series of fault blocks composed of Cambrian and volcanic rocks in fault contact with the Copper Belle monzonite porphyry and blocks of late upper Paleozoic rocks. At the north end of the ridge is a fault block of felsitic rock, some of which preserves pyroclastic textures and is therefore referred to the Sugarloaf quartz latite and which rests on the Escabrosa limestone and an underlying sliver of Abrigo limestone. The intervening fault dips westward about 40°. Small blocks of Escabrosa limestone, Abrigo limestone, Bolsa quartzite, and highly altered felsitic rocks, whose reference to the Sugarloaf quartz latite is much more dubious, occur along the west base of the ridge for more than a mile. They are not in contact with the plate of Escabrosa limestone capping the ridge, but they are essentially on strike of the fault blocks to the north. It seems likely that these masses, like the ones just described, constitute tectonically higher fault plates than the ones forming the ridge crest. A sheet of Horquilla limestone forms the lower southern spur of Gleeson Ridge at the common southern corner of secs. 32 and 33, T. 19 S., R. 25 E., and thence extends southward into sec. 5, T. 20 S. If, as seems reasonable, this mass is a part of the same thrust sheet that caps the ridge farther north, the sequence inferred at the north is confirmed, for the Bolsa quartzite at the southwest side of this ridge unquestionably rests on this plate of Horquilla limestone.

The sketch maps and sections of plates 11 and figures 7–9 show the complexity of the structure in the area east of Sugarloaf Hill and southeast of Gleeson. These maps, though merely planimetric sketches, are presented as samples of the relations over most of the Courtland–Gleeson area. During this survey the thrust faults of the Dragoon Mountains were first encountered in this area. Although the lithologic distinction of most of the formations involved is fairly clear, the extreme fragmentation of the rocks led to considerable skepticism by Mr. Cannon and myself as to the structural inferences seemingly demanded by the mapping. We accordingly collected many scores of fossil lots from this area, in order to check our determination of the identity of the several formations involved. In view of the confirmation of practically all of our stratigraphic determinations by the fossil identifications, I feel more confidence in the accuracy of the mapping in this area than in any other part of the region shown on plate 5.

It is evident that in this area there is a huge breccia of fault blocks, arranged in almost random stratigraphic order. Although many of the faults have high-angle dips, there can be little question that the dominant structure, at least in the northern and eastern parts of the breccia area, is that of a pile of thin plates dipping generally to the south at relatively low angles. These thin plates, which are a few scores or tens of feet in thickness and the origins of which are thousands of feet away from the origins of neighboring blocks, obviously could not have been brought into their present relations as independent thrust masses. They seem only to be explicable as fragments that broke off the base of an overriding thrust block as it traversed the area. The great range in stratigraphic origin of many of the individual sheets that are now in contact seems to imply that the overriding block was cut at a high angle to bedding by the fault upon which it was advancing. The ubiquity of fragments and small outcrops of the Sugarloaf quartz latite suggests that this rock was generally available for incorporation in the giant breccia—a suggestion, in turn, that locally it might be the underlying block of the entire thrust mass. In absence of drilling, however, I know of no way of testing this idea.

Although it would be difficult to prove, there seems to be a general southerly or southwesterly dip of the individual blocks of the thrust breccia in secs. 4, 5, 9, and the NE¼ sec. 8, T. 20 S., R. 25 E. If this is indeed the general dip, it would suggest that the large body of quartz latite composing Sugarloaf Hill forms a higher member of the thrust assemblage. There are reasons, however, for doubting this interpretation. As noted in the preceding paragraph, the widespread distribution of the Sugarloaf quartz latite in the breccia area, both as included blocks and as the lowest locally visible structural unit in many places, suggests that this formation may have formed the surface of the lower plate over which the thrust traveled. The only contact exposed which might be interpreted as the eastern boundary of the mass of quartz latite composing Sugarloaf Hill is a fault in the southeastern part of sec. 5. As shown on the sketch map of figure 8, this fault brings the Sugarloaf over the narrow sliver of Bolsa quartzite. Although the 45° W. dip of the fault is essentially parallel to that of the lower fault that brings the Bolsa on top of the Colina limestone (as one of the plexus of faults that characterizes the breccia zone), it seems possible that the overriding quartz latite block may be really a part of the generally underlying terrane, broken and upthrust during the faulting but not necessarily constituting a higher sheet of the thrust pile. If it were such a higher sheet, it would seem difficult to explain the lower tectonic levels at which the quartz latite is generally found toward the east and reconcile these with the heterogeneity of the breccia as a whole. This interpretation is not proved but seems sufficiently probable to justify the hypothetical extension of the short fault observed in sec. 5 for more than a mile to the southeast beneath the alluvium. (See pl. 11 and fig. 8.)

The interpretation of the mass of Sugarloaf Hill as a part of the basement over which the breccia travelled may be favored by the rather considerable thickness of this mass; its easterly dip, as contrasted with the westerly dip of the blocks of Sugarloaf quartz latite along the west base of Gleeson Ridge; the evidence of apparently small eastward-dipping faults along the west base of Sugarloaf Hill; and the fact that fewer thrust sheets need be postulated on this interpretation than on any other. Accordingly, this is the working hypothesis here adopted, although in absence of drilling data or other underground information it cannot be proved.

One further point in connection with the mass of Sugarloaf Hill seems to merit discussion. Although eastward-dipping faults along the western base of the hill may imply thrusting, there is no evidence that they have other than trivial displacement. To the north, in both the Gleeson and Courtland districts, wherever the two formations are in contact, the Sugarloaf quartz latite is faulted against the Copper Belle monzonite porphyry. It might therefore be inferred that a lower thrust sheet of Copper Belle underlies the quartz latite body on Sugarloaf Hill. Such an inference cannot be given much weight, however, for no convincing evidence exists that the Copper Belle was emplaced as a large mass. The Sugarloaf quartz latite is much younger and could therefore have been locally deposited on the porphyry, and the fact that the Copper Belle is nowhere exposed more than a few hundred feet south of the line between Tps. 19 and 20 S. does not necessitate a major thrust fault between this formation and the volcanic rocks.

STRUCTURAL FEATURES YOUNGER THAN THE THRUST FAULTS

GENERAL STATEMENT

Because the faults that cut the formations younger than the thrusting trend between westward and north-northwestward, like the thrust faults and the structures associated with them, it is by no means certain that all the younger faults have been recognized as such in areas where only rocks of prethrust age are present. Furthermore, although on regional grounds it seems likely that the basins are separated from the major mountain blocks by normal faults of "Basin and Range" type, the widespread pediments have transected these faults and buried most of them beneath pediment gravels. Accordingly, no connected account of the postthrusting structures seems possible.

STRUCTURES AFFECTING THE S O AND PEARCE VOLCANICS

In the area between Outlaw Mountain and Reeves Ranch, the S O volcanics and associated sedimentary rocks are tilted to angles of 20° on the average but locally as steeply as 50° and are broken by faults. As mentioned in the description of the S O volcanics, the unconformities beneath and between the various members of this formation are such as to suggest that some of the tilting and faulting was older than and some concurrent with the volcanism; but inasmuch as the upper member is also involved, the structural disturbance was partly younger as well. The tilting is so irregular in trend and so intimately associated with the faulting as to suggest that it was probably caused by surficial adjustments to movements of the underlying magma during and following the volcanic episodes.

Near Pearce, the Pearce volcanics are also irregularly tilted, generally to moderate amounts but locally to angles as high as 60°. It seems probable that most of these structures, too, are associated in origin with the volcanic activity and do not reflect regional stresses.

BASIN AND RANGE FAULTS

The line of hills extending south-southeast from Three Sisters Buttes to Ash Creek Ridge continues on the same trend to the Swisshelm Mountains east of the mapped area. A crudely parallel alinement can also be recognized for the group including Township Butte. These buttes rise above the alluvial fill of Sulphur Spring Valley like islands from the sea; they are clearly the peaks on mountain ridges nearly drowned in alluvium. They are interpreted as probably fault block mountains. This inference is not demonstrated, of course, as the trend is about parallel to the dominant regional strike and might thus be explained as a result of differential erosion rather than faulting. But the western border of the Dragoon Mountains near South Pass is marked by faults of similar trend, and the roughly parallel fault bounding the S O volcanics near the S O Ranch is clearly younger than the Gila conglomerate to the north. Accordingly, it is considered likely that both the Dragoon Mountains and the nearly buried ridges to the east are fault-block mountains.

The faults along the west side of the southern Dragoon Mountains are only sporadically exposed. In many places they are beveled by pediment gravels. No evidence of similar faults was seen on the east side of the Dragoon Mountains.

The obscurity of these faults is illustrated by the results of drilling in the Tombstone area. At the eastern end of Tombstone the gravel overlap on the Bisbee formation is well exposed and is a relatively smooth surface of low relief. Yet drilling west of the Courtland road and less than 1,000 feet north of the exposed overlap disclosed a depth of more than 1,000 feet of gravel. Clearly an eastward-trending fault lies concealed beneath the gravel cover; the downthrown side, toward the north, preserves Gila conglomerate or related beds, whereas the surficial gravels show no sign of faulting and are clearly encroaching on the pediment to the south. For these reasons the highland areas are likely blocked out by faults of the Basin and Range type, even though few of them can now be demonstrated. Their obscurity is readily explicable on the assumption that the faulting ceased long enough ago (early Pleistocene?) to allow later erosion to reduce the fault relief and for younger gravels to bury the faults, in contrast with many areas elsewhere in the Basin and Range province where faulting has continued to the present.

GEOLOGICAL HISTORY

The following paragraphs summarize the geological history of the area insofar as I have been able to decipher it. The summary is admittedly rather categorical, but the dubious points are adequately pointed out in the stratigraphic and structural sections of the report, where the reasons for the conclusions that are here rather dogmatically expressed are more fully discussed and the conclusions qualified.

The legible geologic history of the area opens with the deposition of the sedimentary rocks and associated siliceous volcanic rocks now represented by the Pinal schist. Whether these rocks are marine or terrestrial is unknown. Either concurrently with their deposition or somewhat later, sills of basaltic rocks were injected into the formation. Perhaps some basaltic lavas are also represented in it. Long prior to Cambrian time the rocks were tightly folded along axes that trend on the average northeasterly, mildly metamorphosed to schist, and injected by small masses of quartz diorite, gneissic granite, and quartz monzonite. The intrusive rocks were also involved in the low-grade metamorphism of the Pinal.

The metamorphism of the Pinal schist probably considerably antedates the beginning of the Cambrian period; although the Apache group is not locally represented, it extends to within a few miles to the north and northwest of this area. The practically unmetamorphosed sedimentary rocks of the Apache group there rest with great unconformity upon the Pinal schist and are disconformably covered by the Troy quartzite, the probably homotaxial equivalent of the Bolsa quartzite. Accordingly, the metamorphism and deep erosion of the Pinal schist preceded the invasion of the Cambrian sea by a time sufficiently long to permit deposition of the Apache and its disconformable overlap by the Troy quartzite.

Although marine waters began to flood the Cordilleran region in earliest Cambrian time or even long before, they did not reach this area until the Middle Cambrian. The Bolsa quartzite doubtless represents the sandy strand deposits of the encroaching sea. With further sinking and doubtless further eastward migration of the shore zone, the local sediments became finer grained, and the strata now included in the Abrigo limestone began to be deposited. As shown by the abundant animal trails and fossils, the depth of the water was not great. The clay and fine sandy sediments of the lower Abrigo eventually gave place to calcareous and dolomitic deposits that constitute the bulk of the formation. No break in sedimentation marks the Middle–Upper Cambrian boundary.

The sea withdrew from the area before the close of Cambrian time, leaving, in the top clastic member of the Abrigo limestone, a probable record of its regressive deposits.

The absence of recognized sediments of the interval between Ordovician and Late Devonian time, together with the lack of any evidence of erosion of the Cambrian deposits, suggests that the area lay near sea level throughout this long interval.

A shallow sea again flooded the area during part of the Late Devonian epoch, as is shown by the rather fine clastic and limy deposits of the Martin limestone. The increase in clastic beds northward suggests that during this epoch the shoreline lay in that direction.

As the lowermost Carboniferous does not seem to be represented in the area, the region seems to have been emergent in this interval. Neither regressive nor transgressive clastic deposits have been recognized as recording this emergence, however.

During the early Mississippian period a clear sea flooded the area, depositing the sediments now classed as the Escabrosa limestone. Judging from the abundance of fossils, the sea was relatively shallow. Rocks of definite late Mississippian age have not been recognized in this area, though certain beds high in the Escabrosa possibly may be deposits of this time. Definitely upper Mississippian rocks are found both to the north and east, but their lithology is not duplicated in this area.

The sea is thought to have withdrawn during the late Mississippian, though it is possible that rocks of this period were indeed deposited and removed by erosion during earliest Pennsylvanian time, for the Horquilla limestone seems not to represent the very earliest part of the Pennsylvanian period.

The area was again submerged in early Pennsylvanian time and apparently continued so throughout the period and for a considerable part of the Permian. The sea was evidently at no time deep, as the limy sediments of the Horquilla, Earp, and Colina are notably rich in fossils, while the Epitaph, though poorly fossiliferous, contains many suggestions of their former presence. The deposits of this sea were dominantly limy. Clastic interbeds in the Earp formation do not seem to record any emergence or even notable shallowing of the sea, nor are they localized near the Carboniferous–Permian systemic boundary. It is possible that the area remained submerged throughout Permian time as later Permian rocks are present both to north and east.

At some time between their deposition and the Early Cretaceous—an interval of at least 70 million years—the rocks of the area were powerfully deformed and later injected by magma from below. The magmas now represented by the Juniper Flat granite, the Gleeson quartz monzonite, the Copper Belle monzonite porphyry, the Cochise Peak quartz monzonite, and the Torquoise granite were emplaced at this time. Andesitic and rhyolitic lavas were also erupted at this time in areas to the north and probably in this one also. These may have been surface representatives of one or more of the intrusions just enumerated, but of this there is no evidence. It is perhaps equally possible that these volcanic rocks, represented by the body east of South Pass, in the Dragoon Mountains, are of earliest Cretaceous age and not genetically connected with these older intrusions. This possibility is suggested by their association with conglomerates like those of the Comanche and is adopted here for convenience, and the volcanic rocks are accordingly classed as Cretaceous(?).

The considerable relief produced by these disturbances (and volcanic eruptions?) was not erased by the time the sea again transgressed the region in the Early Cretaceous. The great variations in thickness of the Glance conglomerate attest to this considerable relief. It is also suggested by the evident local northward thickening of the Morita formation beneath the Mural limestone in the northern Mule Mountains, where the pre-Mural Comanche strata north of the synclinal axis near Gadwell Spring greatly exceed in thickness those on the south flank of this syncline. Although, as shown by the northward thinning of the Mural limestone in the Mule Mountains and by the presence of estuarine or brackish-water faunules to the north, the Comanche sea encroached northward on the area, there is no stratigraphic evidence that the base of the Comanche series is represented by younger rocks at Tombstone and in the Dragoon Mountains than in the Mule Mountains. Local relief, as demonstrated in the Mule Mountains might actually permit the landward deposits, which in any event seem partly estuarine or terrestrial, to be older than the basal Cretaceous of the Mule Mountains.

The Comanche sea was doubtless shallow and received huge quantities of mud and sand. Whether or not the sediments herein referred to the Bisbee formation include land-laid materials, as I believe, the subsidence of the basin must have been about equally great throughout the area here considered, for the grain size of the rocks is about the same whether they were laid under marine conditions, as in the Morita of the Mule Mountains, under estuarine, as in the lower part of the Cretaceous of Tombstone, or in the apparently nonmarine parts, as in the eastern foothills of the northern Dragoon Mountains. Modifications, either of the coastal form or of the source of sedimentary supply, allowed the local development of limy sediments such as those of the Mural limestone. These do not, however, represent deep-water deposits, as they contain abundant fossils of groups that are considered reef dwellers.

The history following the retreat of the Early Cretaceous sea cannot be confidently read even in terms of correlating the local events. It is all the more difficult to assign these to specific geologic epochs, for no fossils are known in rocks whose ages lie between Early Cretaceous and late Pliocene.

Marine and terrestial deposits of Late Cretaceous age are known in the general region: northern Sonora, Patagonia Mountains, and Aravaipa district. It is probable that rocks of this age were deposited here also, but evidence is wholly lacking. The unconformity at the base of the Bronco volcanics is clear evidence of crustal deformation and subsequent erosion after the Bisbee formation was deposited. A mild discordance between Comanche and Upper Cretaceous rocks is reported in Sonora, and andesitic rocks interfinger with fossiliferous Upper Cretaceous strata to the north, so that it is possible that the Bronco volcanics are Upper Cretaceous. In Sonora some rhyolitic volcanic rocks have also been referred to the Upper Cretaceous. But the fold axes of pre-Bronco age trend nearly east, as do post-Late Cretaceous fold axes in Sonora; so it is equally or more probable that the Bronco volcanics are post-Cretaceous. The intrusions of the granite gneiss near Jordan and Fourr Canyons and of the granitic mass in Ash Creek Ridge cannot be dated accurately but are presumed to have taken place in early Tertiary time, while the post-Comanche–pre-Bronco deformation was going on. In summary, it is assumed, with doubt, that this area did receive Upper Cretaceous deposits but that these were all removed by erosion after the pre-Bronco folding and the intrusions near Jordan and Fourr Canyons had taken place.

As hitherto noted, the correlation of Sugarloaf quartz latite and andesite with the andesite and quartz latite of the Bronco is speculative. But as both formations appear to antedate the thrust faulting, it seems justifiable to postulate a rather widespread burial of the country by volcanic rocks during the early Tertiary.

Perhaps during the first half of the Tertiary a major deformation of the rocks took place. There is a probability that the axes of the earlier folding and mild thrusting of this epoch were along generally eastward trends but that later the compression shifted to more northerly axes. It seems that any reasonable reconstruction of the rocks to depth on the basis of their present attitudes and distribution requires that the observed crust was shortened by several miles. There is a strong suggestion that much of the surficial faulting took place while the bedded rocks were being stripped off the basement. Much bedding faulting took place, and I infer that it was in this way that the Bisbee rocks along the east side of the Dragoon Mountains were sufficiently uplifted to allow them to overfold into a recumbent syncline. Over this southward-plunging syncline the Dragoon thrust was able to ride along a zone of transcurrent faulting. It probably emerged along a line west of Courtland and about through Gleeson, leaving a train of gigantic breccia fragments on the overridden Sugarloaf quartz latite. In these great blocks, distributed almost at random, are the bodies of mineralized rock containing the ore deposits of Courtland and Gleeson.

Perhaps in middle Tertiary time the Uncle Sam porphyry was injected along the old thrust planes near Tombstone, locally cross-cutting the older rocks in an intrusive plexus. This must have taken place under a relatively shallow cover in order to account for the fine grain of the intrusion. Later dikes of andesite porphyry cut the rocks and presumably broke through to the surface to build a volcanic pile. The thickening of the cover thereby produced allowed a slower cooling of the Schieffelin granodiorite at the same crustal level that had permitted the quenching of the Uncle Sam porphyry. At this time the ore deposits of Tombstone were most likely formed. It seems likely that the quiet emplacement of the Stronghold granite took place at about the same time as the Schieffelin granodiorite. Evidently the magma welled up from below, making way for itself by passive stoping with only gentle up-bowing of the surface.

If the andesite porphyry intrusion does indeed imply the formation of a middle Tertiary volcanic cover, it must be admitted that all evidence of this cover has been eroded away. The S O volcanics are most probably younger than the erosion of the roof rocks of the Schieffelin granodiorite, and the Pearce volcanics are younger than the Stronghold granite. So, too, the rhyolite intrusions near and south of Tombstone were formed after erosion to a surface probably not far above that of the present.

In perhaps Miocene time the area was widely covered by more volcanic deposits, represented now by the S O and Pearce volcanics. Accompanying their extrusions, the district was disturbed, and small folds and tilted fault blocks were formed perhaps by movement of the magma at depth. The mineralization at Pearce was probably of this epoch.

Erosion followed; and then, at a time probably early in the Pliocene and under influence of regional rather than local forces, the country was riven by great normal faults. These blocked out the major topographic features that have survived to the present day.

The intermontane troughs formed at this time were largely filled by fan gravels and associated playa deposits from the adjacent mountains. The landscape in late Pliocene time must have closely resembled that of the present day, except that there were a few basaltic cones and associated lava flows. Minor faulting probably persisted locally after the basin filling began.

The Gila conglomerate represents the deposits of this time, and it continued to accumulate into Pleistocene time.

During the Pleistocene a lake formed in the Willcox Playa, and there may well have been similar lakes in the San Pedro Valley. If so, however, all records of them have been removed by later Pleistocene and Recent erosion. It is likely that the integration of the San Pedro drainage with that of the Gila River took place some time during the Pleistocene. This permitted the scouring out of much of the San Pedro Valley fill and the development of the Tombstone pediment. Later lowering of the San Pedro River allowed the dissection of this pediment to the level of the Whetstone surface and still later to that of the Aravaipa stage.

Beginning about 1880 renewed incision of the Aravaipa terraces took place.

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